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AN EXPERIMENTAL  
DETERMINATION OF THE  
LOW-LEVEL CHARACTERISTICS  
OF IN23B CRYSTALS

BY  
BRUCE ALBERT RUSHLOW

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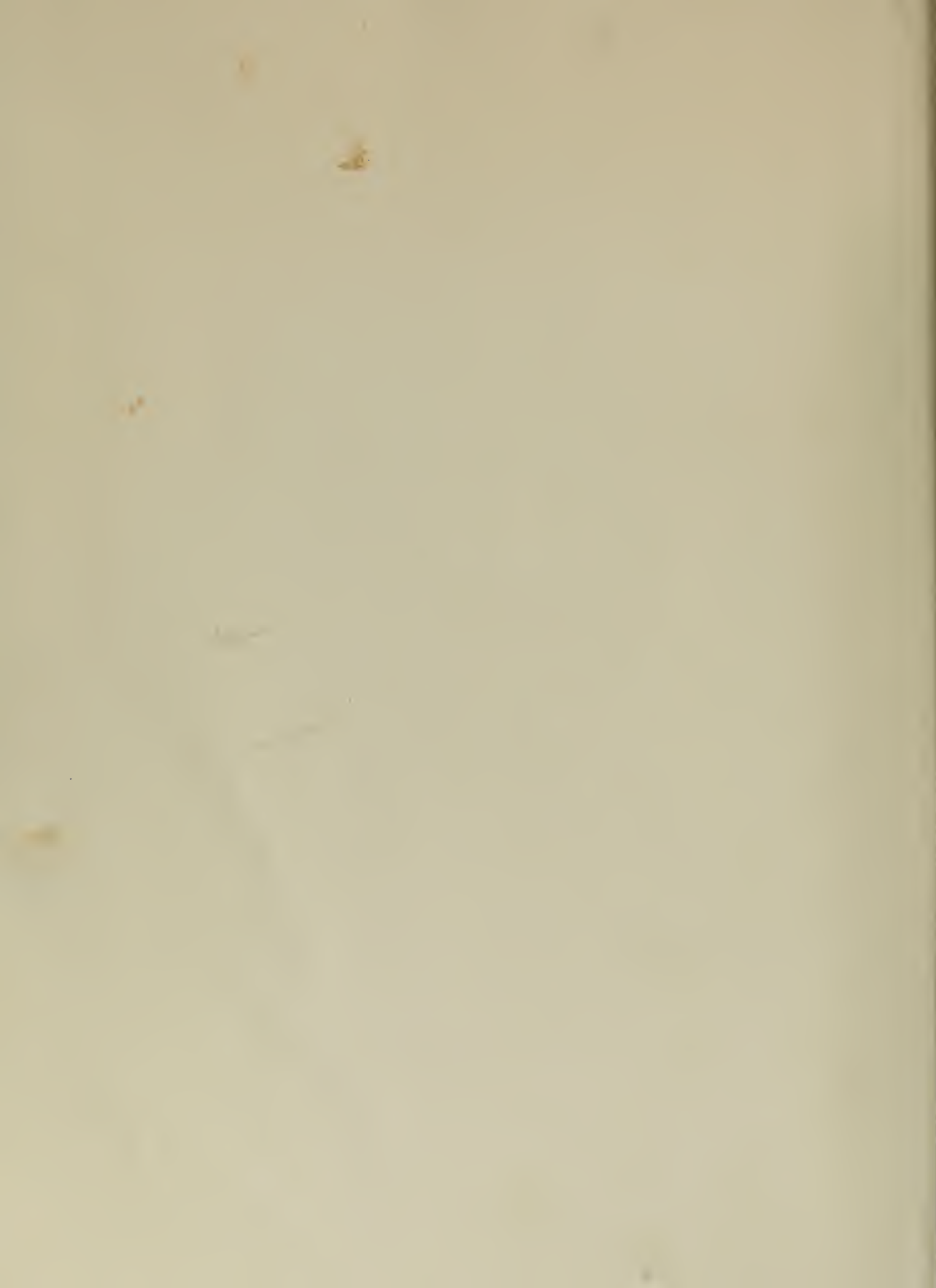
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AN EXPERIMENTAL INVESTIGATION  
OF THE LOW-LEVEL CHARACTERISTICS OF  
IN230 CRYSTALS

by

Bruce Albert Rushlow

AN ESSAY  
SUBMITTED TO THE ADVISORY BOARD OF THE  
SCHOOL OF ENGINEERING, THE JOHNS HOPKINS UNIVERSITY  
IN CONFORMITY WITH THE REQUIREMENTS FOR  
THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING

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## INTRODUCTION

The development of microwave electronics equipment during World War II returned the crystal rectifier to a place of prominence in the field of electronics. There is at present no component in the development stage that will lessen the crystal rectifier's importance.

Many types of crystal rectifiers have been developed in the past ten years. Among these the high sensitivity, low burnout 1N23B is probably the most widely used. Though used primarily as a mixer crystal, it is also used as a low-level detector with good results. However, a search for specific information in the low-level video characteristics revealed very little useable information.

In this paper a summary of the general theory of low-level video crystals is given, followed by the experimental determination of the low-level video characteristics for the 1N23B crystal. The experimental results are summarized, and recommendations as to the proper use of these crystals in voltage and power amplification units are given.





## II

### OUTLINE OF THEORY OF CRYSTAL RECTIFIERS

#### The Barrier-Layer Rectification Principle (2, 27, and 8)\*

A typical crystal rectifier unit is shown in Figure 1. Figure 2 gives the conventional polarity of crystal cartridges. The unit depends for its action on the electrical characteristics of the semiconductor.

A semiconductor is a substance which offers low impedance to the flow of current in one direction and high impedance to the flow of current in the opposite direction. Rectification results from the presence, in the semiconductor adjacent to the metal whisker contact, of a potential barrier or hill which current carriers, electrons or holes, must overcome in order to flow across the metal-semiconductor junction. The low impedance direction is that in which the carriers flow from the semiconductor to the metal whisker.

If a voltage is applied to the rectifier in the low impedance or forward direction it tends to reduce the potential barrier and thus lower the crystal impedance. If a voltage is applied in the reverse direction it tends to increase the barrier layer and thus increase the impedance to current flow. A typical voltage-current curve resulting from this action is shown in Figure 3.

---

\* Parenthesized numbers refer to the bibliography.

# THE HISTORY OF THE UNITED STATES

The following table shows the population of the United States in 1790, 1800, and 1810.

1790 1800 1810

1790 1800 1810

The first column shows the population in 1790, the second in 1800, and the third in 1810.

of the population.

A comparison of the population in 1790, 1800, and 1810 shows that the population of the United States was increasing rapidly.

As the population of the United States was increasing rapidly, it was necessary to find a way to count the population.

One of the first steps was to divide the country into small districts, each of which was to be counted separately.

Then the population of each district was counted, and the results were added together to find the total population.

At first, the population was counted by the number of heads of families, but this was not very accurate.

Later, the population was counted by the number of persons, and this was more accurate.

The first census was taken in 1790, and the results were published in 1792.

Since that time, the population of the United States has been counted every ten years.

1790.

It is a curious fact that the population of the United States was not counted until 1790.

Before that time, the population was estimated by the number of heads of families.

But this was not very accurate, and it was not until 1790 that the population was counted by the number of persons.

Since that time, the population of the United States has been counted every ten years.

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1790.

A comparison of the population in 1790, 1800, and 1810 shows that the population of the United States was increasing rapidly.

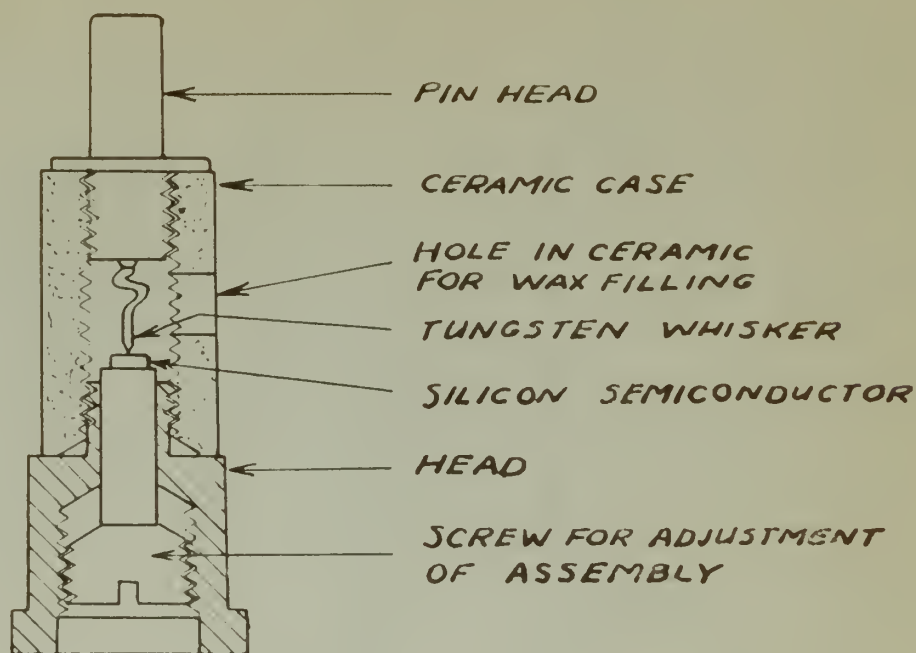


FIGURE 1. - CERAMIC CARTRIDGE

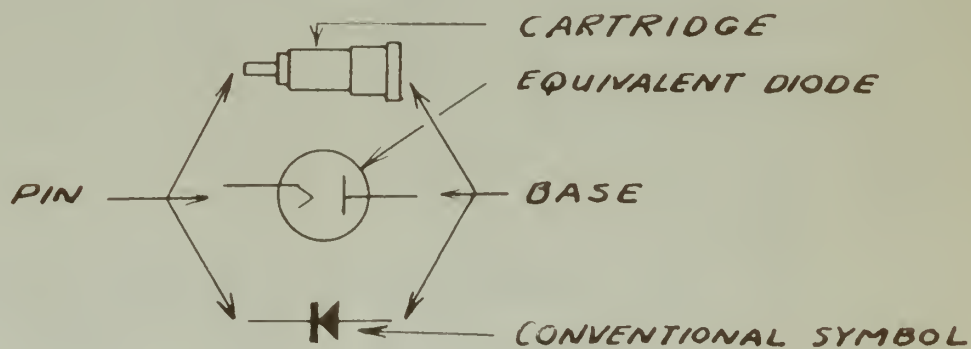


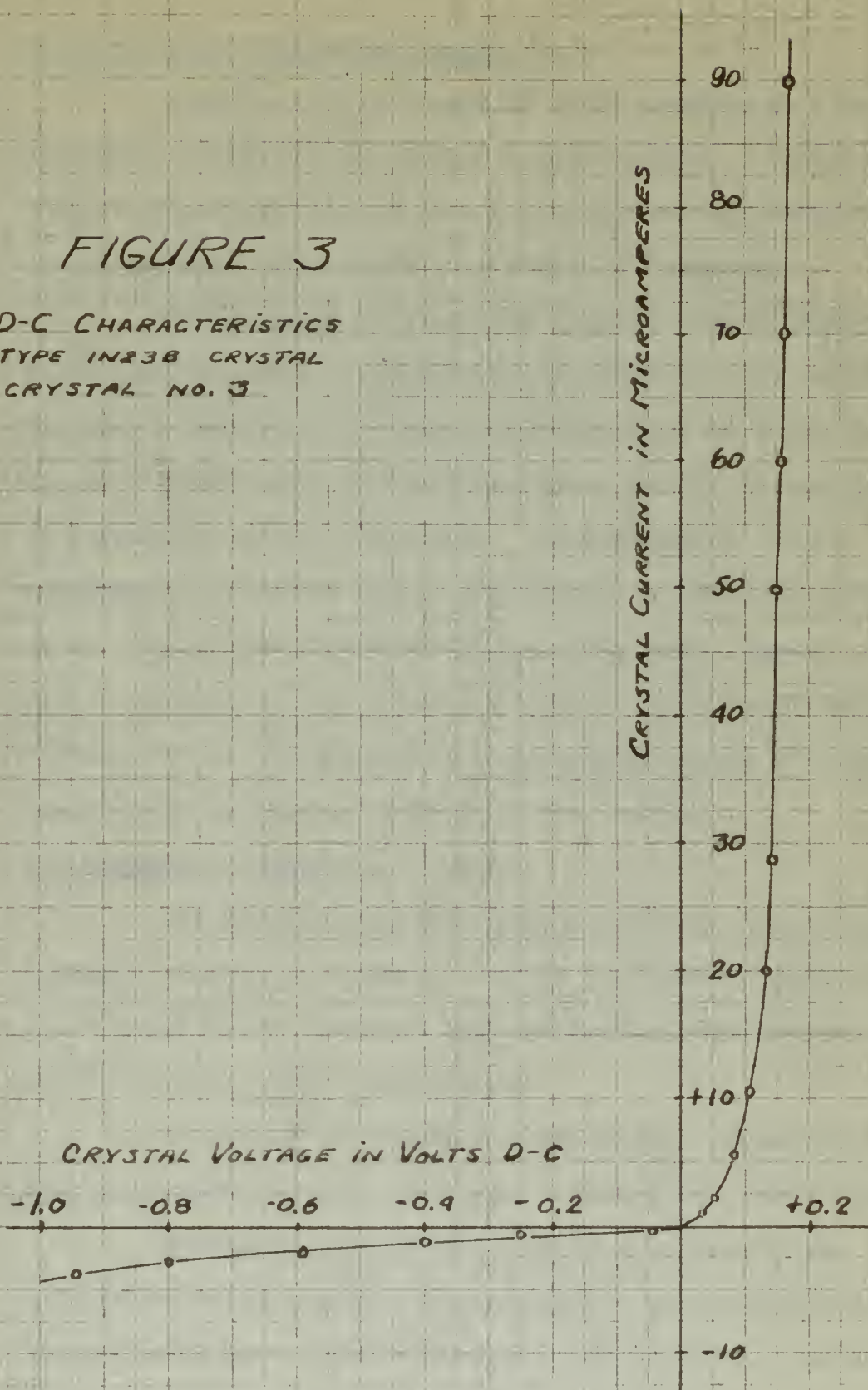
FIGURE 2. - CARTRIDGE POLARITY

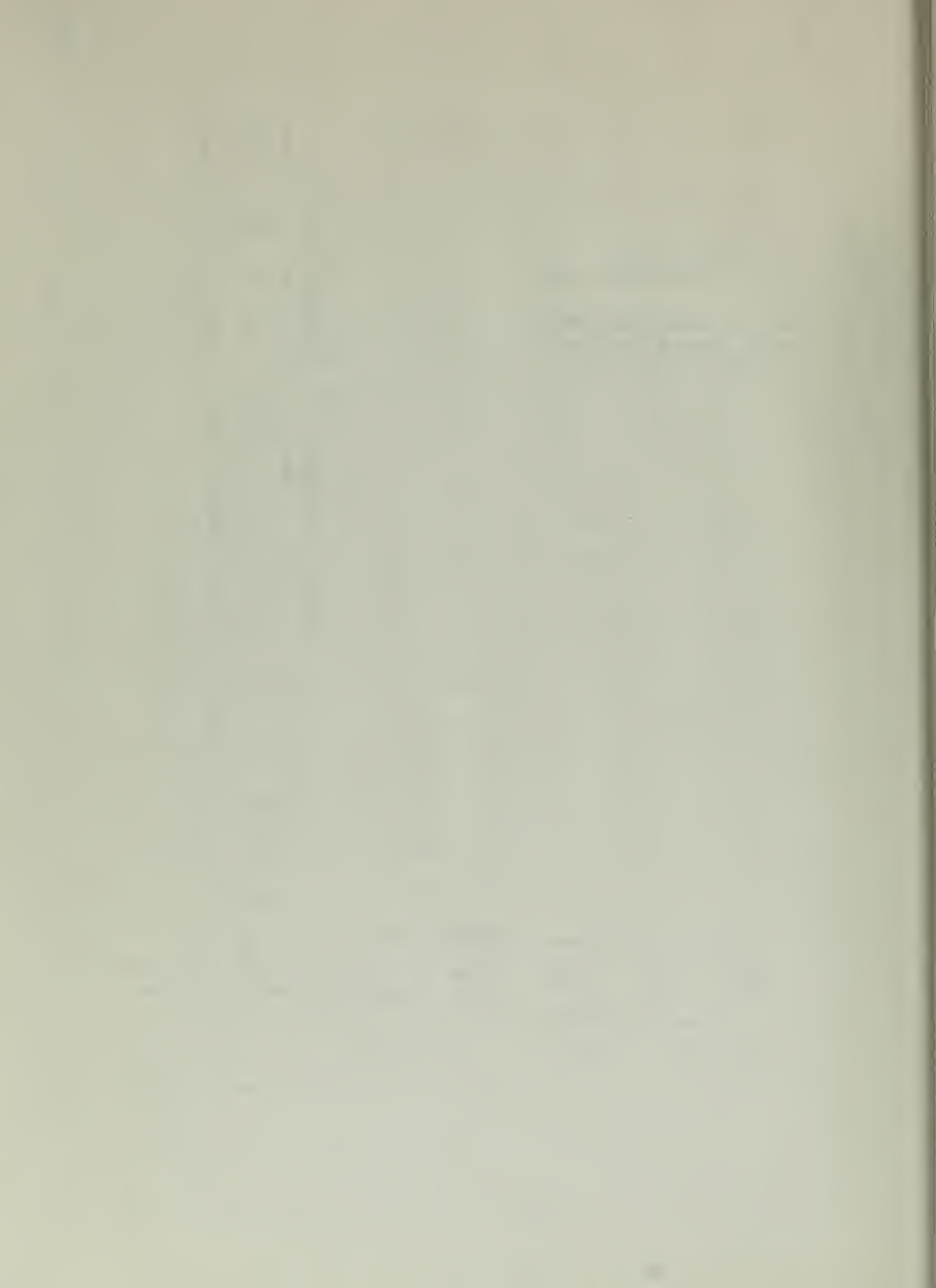




# FIGURE 3

D-C CHARACTERISTICS  
TYPE 1N23B CRYSTAL  
CRYSTAL NO. 3





### The Crystal as a Square-Law Detector (1, 2)

Detecting devices depend for their operation on a non-linearity of their voltage-current characteristics. A detector is called a square-law detector when its voltage-current characteristic at the operating point can be approximated by a parabola.

The output of the square-law detector will be composed of a d-c component and an a-c component proportional to the square of the input voltage for each frequency component of the input plus the sum and difference frequencies of every possible combination of frequencies in the input signal. The magnitude of the a-c component in the output will be proportional to the second derivative of the characteristic curve at the operating point. Maximum output will be obtained when the operating point is the point of maximum curvature of the voltage-current characteristic curve. The operating point may be adjusted by means of the bias voltage.

### The Equivalent Circuit (2, 5, and 6)

The generally accepted equivalent circuit of the crystal rectifier is shown in Figure 4. This is the simplest possible form and is based on the assumption that the whisker makes single-point contact with the silicon semiconductor.

The barrier resistance  $R$  is non-linear. It decreases with application of forward bias, and increases with reverse bias.

The spreading resistance  $r$  is the resistance of the semiconductor-metal contact, and is caused by the constriction of current flow lines in the semiconductor near the whisker contact



where  $A$  is the matrix of the linear transformation  $T$  relative to the basis  $B$ .

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Abstract: The purpose of this study was to determine the effect of a 12-week training program on the physical fitness and health-related quality of life of sedentary middle-aged men. The study was a randomized controlled trial. The participants were divided into two groups: a control group and an exercise group. The exercise group performed a 12-week training program consisting of aerobic and resistance exercises. The control group did not exercise. The physical fitness and health-related quality of life were measured at baseline and after 12 weeks. The results showed that the exercise group had significantly higher physical fitness and health-related quality of life than the control group after 12 weeks. The findings suggest that a 12-week training program can improve physical fitness and health-related quality of life in sedentary middle-aged men.

As the question arises how the government is to be financed

The dimensions and life span of the individuals are the same as in

(4) and (5) are also satisfied.

Integrat. med. 30: e20022 (2018)

condition is shown in Figure 4. This is the highest possible level

— *Journal of the American Medical Association*

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*For application of Theory 2, see footnote 10.*

doi:10.1017/S002229240000209

See [university and its role in the 21st century](#) for more information.

Source: Data from the author's survey of 100 respondents.

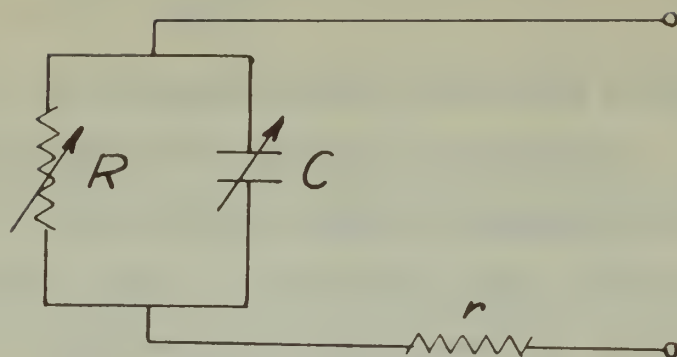


FIGURE 4. - EQUIVALENT CIRCUIT OF  
A CRYSTAL RECTIFIER

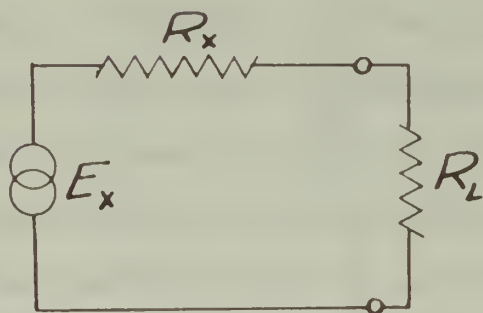
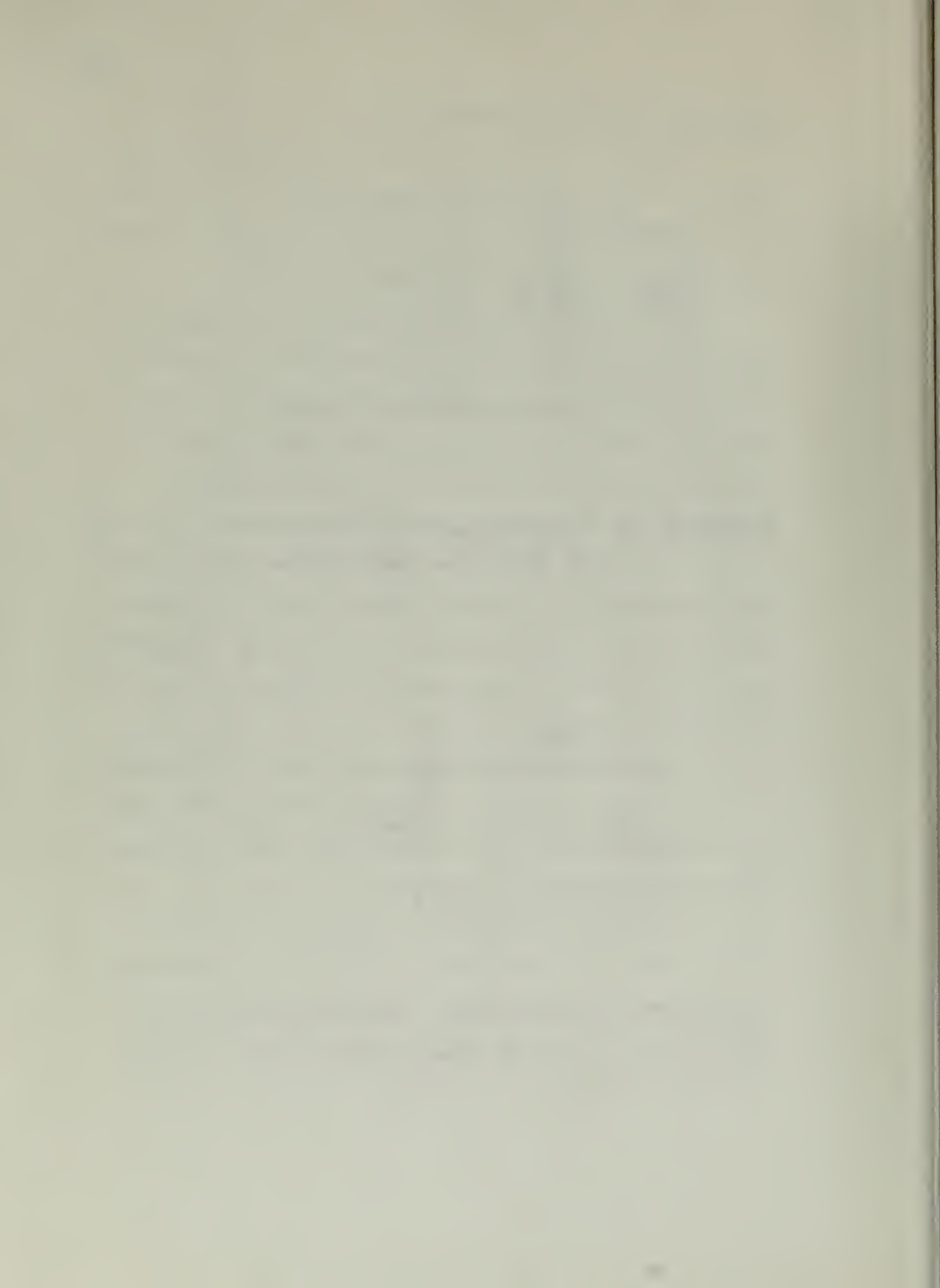


FIGURE 5. - VOLTAGE GENERATOR CIRCUIT  
OF A VIDEO CRYSTAL



point. If the contact is considered to be circular (8),  $r$  is given by

$$r = \frac{1}{4\sigma a} \quad (\text{ohms}) \quad (1)$$

where  $\sigma$  is the semiconductor conductivity in  $(\text{ohm-cm})^{-1}$  and  $a$  is the radius of the contact in centimeters.\*

The non-linear barrier capacitance  $C$  is a result of the storage of charge in the boundary layer. The value of  $C$  at zero bias is approximately 10 micromicrofarad. It is relatively independent of variations in applied voltage (21). At high frequencies  $C$  acts as a by-pass to  $R$ . At video frequencies  $C$  plays no important part in the rectification phenomenon.

When a crystal is operating as a square-law detector it is convenient to represent it as a four terminal network in which the video and microwave terminals are considered isolated from each other (7). Since the microwave energy source is not affected by the output load, it is possible to represent the crystal as a voltage generator of output voltage  $E_x$  proportional to the input power, and an internal resistance of  $R_x = R + r$ . This is shown in Figure 5.  $E_x$  and  $R_x$  are obviously both functions of crystal bias, and thus this voltage generator concept is good only for the bias specified. The load is connected as shown in the figure.

---

\* See Appendix C of (2) for the spreading resistance of an elliptical contact. (8) discusses the knife edge contact of the British "Red Dot" crystal.





### Low-Level Properties

From Figure 4 it is seen that the output impedance of the crystal is

$$Z = r + \frac{1}{\frac{1}{R} + j\omega C} \quad (\text{ohms}) \quad (2)$$

At video frequencies the  $j\omega C$  term is small compared to  $\frac{1}{R}$ . Thus the video impedance becomes a pure resistance and is given by

$$Z = R_x = R + r \quad (\text{ohms}) \quad (3)$$

The current sensitivity of a crystal  $\beta$  is defined as the ratio of the short circuit rectified current to the absorbed microwave power,

$$\beta = \frac{i_s}{P} \quad \frac{(\text{microamperes})}{(\text{microwatt})} \quad (4)$$

Berlinger (7), and Lawson et al (14) have shown that the variation of  $\beta$  with bias may be expressed as

$$\beta = \beta_0 \cdot \frac{1}{1 + \frac{\omega^2 C^2 r R^2}{R + r}} \quad (5)$$

where  $R$ ,  $r$ , and  $C$  are as previously defined, and  $\beta_0$  is the current sensitivity at zero bias.

The crystal detector is a noise generator as well as a microwave converter. Berlinger (7) has derived an expression for the output signal-to-noise voltage ratio of a crystal-video receiver in which he defines a quantity called the Figure of Merit,  $M$ .

Problem 1

The system is defined by the following equations:

for  $t \geq 0$

$$\dot{x} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u \quad (1)$$

where  $x$  is the state vector and  $u$  is the input.

The initial condition is  $x(0) = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ .

$$y = \begin{bmatrix} 1 & 1 \end{bmatrix} x \quad (2)$$

The output  $y$  is the sum of the state components.

Find the response  $y(t)$  for  $t \geq 0$ .

$$y = \begin{bmatrix} 1 & 1 \end{bmatrix} x \quad (3)$$

Substituting (1) into (3), we get:

$$\dot{y} = \begin{bmatrix} 1 & 1 \end{bmatrix} \left( \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u \right) \quad (4)$$

Since  $x(0) = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ , we have  $y(0) = 2$ .

The system is a simple integrator.

Therefore, the response is:

The output  $y(t)$  is the sum of the state components.

The output signal-to-noise voltage ratio is given by

$$\frac{E_s}{E_n} = \frac{\beta P R_x}{\sqrt{4kTB(R_x t + R_a)}} \quad (6)$$

- $E_s$  Signal voltage output  
 $E_n$  Noise voltage output  
 $R_a$  Equivalent noise resistance of the receiver, set by JAN specifications at 1,200 ohms.  
 $k$  Boltzmann's constant,  $1.38 \times 10^{-23}$  Joules/°K  
 $T$  Temperature of  $R_a$  in degrees Kelvin  
 $B$  Noise bandwidth of receiver in cps.  
 $t$  Crystal noise temperature\*

From Equation 6 all the crystal parameters are lumped together by Berlinger and called the Figure of Merit,

$$M = \frac{\beta R_x}{\sqrt{R_x t + R_a}} \quad (7)$$

Smith (25) has shown that  $t$  is approximately equal to 1.0 within the bias region used in the following experiments. The value of 1.0 will be used throughout the paper.

From Equation 6 it is seen that for a given receiver operating at a constant temperature, and for a specified signal-to-noise voltage output ratio,  $M$  is inversely proportional to  $P$ .

$$M = \frac{K}{P} \quad (8)$$

---

\* By definition  $t$  is the ratio of the available noise power output of the crystal to that of a resistor at room temperature. Though it is not a temperature, the term "noise temperature" is commonly accepted and widely used.



(1)

$$\frac{F_2}{F_1} = \frac{B^2 R^2}{\sqrt{4AB(R^2 + R_0^2)}}$$

1. The effect of temperature on the rate of reaction is studied by measuring the rate constant  $k$  at different temperatures. The rate constant is determined from the slope of the line obtained from a plot of  $\ln k$  versus  $1/T$ . The rate constant is found to be  $1.5 \times 10^{-3} \text{ s}^{-1}$  at  $300 \text{ K}$  and  $2.5 \times 10^{-3} \text{ s}^{-1}$  at  $350 \text{ K}$ . The activation energy  $E_a$  is calculated to be  $50 \text{ kJ mol}^{-1}$ .

2. The effect of temperature on the rate of reaction is studied by measuring the rate constant  $k$  at different temperatures. The rate constant is determined from the slope of the line obtained from a plot of  $\ln k$  versus  $1/T$ . The rate constant is found to be  $1.5 \times 10^{-3} \text{ s}^{-1}$  at  $300 \text{ K}$  and  $2.5 \times 10^{-3} \text{ s}^{-1}$  at  $350 \text{ K}$ . The activation energy  $E_a$  is calculated to be  $50 \text{ kJ mol}^{-1}$ .

(2)

$$\frac{B^2 R^2}{R^2 + R_0^2}$$

3. The effect of temperature on the rate of reaction is studied by measuring the rate constant  $k$  at different temperatures. The rate constant is determined from the slope of the line obtained from a plot of  $\ln k$  versus  $1/T$ . The rate constant is found to be  $1.5 \times 10^{-3} \text{ s}^{-1}$  at  $300 \text{ K}$  and  $2.5 \times 10^{-3} \text{ s}^{-1}$  at  $350 \text{ K}$ . The activation energy  $E_a$  is calculated to be  $50 \text{ kJ mol}^{-1}$ .

4. The effect of temperature on the rate of reaction is studied by measuring the rate constant  $k$  at different temperatures. The rate constant is determined from the slope of the line obtained from a plot of  $\ln k$  versus  $1/T$ . The rate constant is found to be  $1.5 \times 10^{-3} \text{ s}^{-1}$  at  $300 \text{ K}$  and  $2.5 \times 10^{-3} \text{ s}^{-1}$  at  $350 \text{ K}$ . The activation energy  $E_a$  is calculated to be  $50 \text{ kJ mol}^{-1}$ .

(3)

$$m = \frac{K}{P}$$

5. The effect of temperature on the rate of reaction is studied by measuring the rate constant  $k$  at different temperatures. The rate constant is determined from the slope of the line obtained from a plot of  $\ln k$  versus  $1/T$ . The rate constant is found to be  $1.5 \times 10^{-3} \text{ s}^{-1}$  at  $300 \text{ K}$  and  $2.5 \times 10^{-3} \text{ s}^{-1}$  at  $350 \text{ K}$ . The activation energy  $E_a$  is calculated to be  $50 \text{ kJ mol}^{-1}$ .

6. The effect of temperature on the rate of reaction is studied by measuring the rate constant  $k$  at different temperatures. The rate constant is determined from the slope of the line obtained from a plot of  $\ln k$  versus  $1/T$ . The rate constant is found to be  $1.5 \times 10^{-3} \text{ s}^{-1}$  at  $300 \text{ K}$  and  $2.5 \times 10^{-3} \text{ s}^{-1}$  at  $350 \text{ K}$ . The activation energy  $E_a$  is calculated to be  $50 \text{ kJ mol}^{-1}$ .

### III

#### TEST EQUIPMENT

In Figure 6 is shown a block diagram of the test equipment.

The microwave generator is a calibrated output TS-13/AP, operated square-wave modulated.

The audio amplifier is a high gain, wide and narrow band TAA-16EA\*. It was operated narrow band and amplified only the fundamental of the crystal output pulse. The input transformer was by-passed, and the output from the crystal loading circuit placed on the input gain control. This input circuit arrangement gave an input impedance to the amplifier of 0.5 megohms. The 6AR6 output rectifier tube was removed and the signal normally applied to its plate was measured by the Hewlett-Packard Model 400A voltmeter.

In determination of the Figure of Merit the TAA-16EA was replaced by a Ballantine voltmeter Model 300 whose input resistance is 0.5 megohms. Also a DuMont Model 208-B oscilloscope was used as an output indicator in place of the Hewlett-Packard voltmeter.

The circuit used to bias and load the crystal is shown in detail in Figure 7. To keep noise pick-up to a minimum it was necessary to place all components enclosed by the dashed line in Figure 7 marked chassis in a completely enclosed metal chassis.

---

\* A circuit diagram of this piece of equipment may be found in "Technique of Microwave Measurements", Montgomery, McGraw-Hill Book Company, p 501.

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группа «Белый дом» (сделала заявление) и была принята в члены организации.

business-related and be aware of potential issues as they arise.

THE UNIVERSITY OF CHICAGO PRESS

Source: U.S. Census Bureau, *Marriage, Divorce, Remarriage in the 1990s*, p. 10.

all wild flocks will be subjected to intensive life study of movements

„...daß die beiden ersten Phasen in der ersten Periode liegen.“

[illegible]

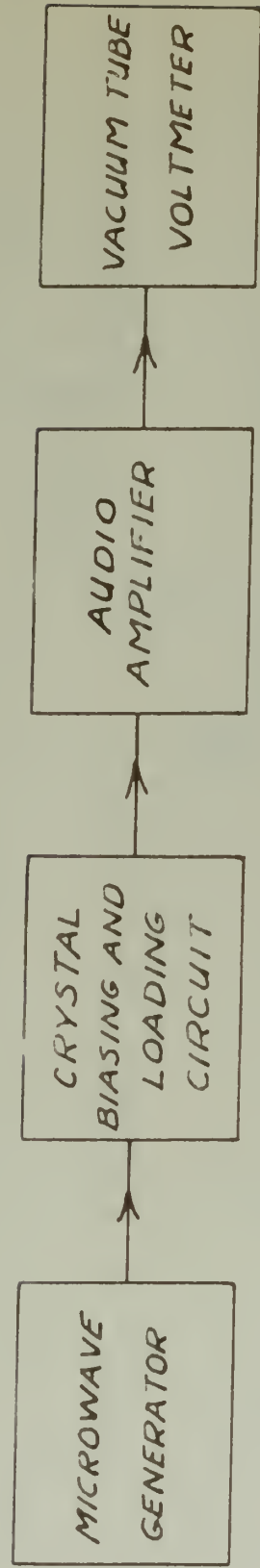
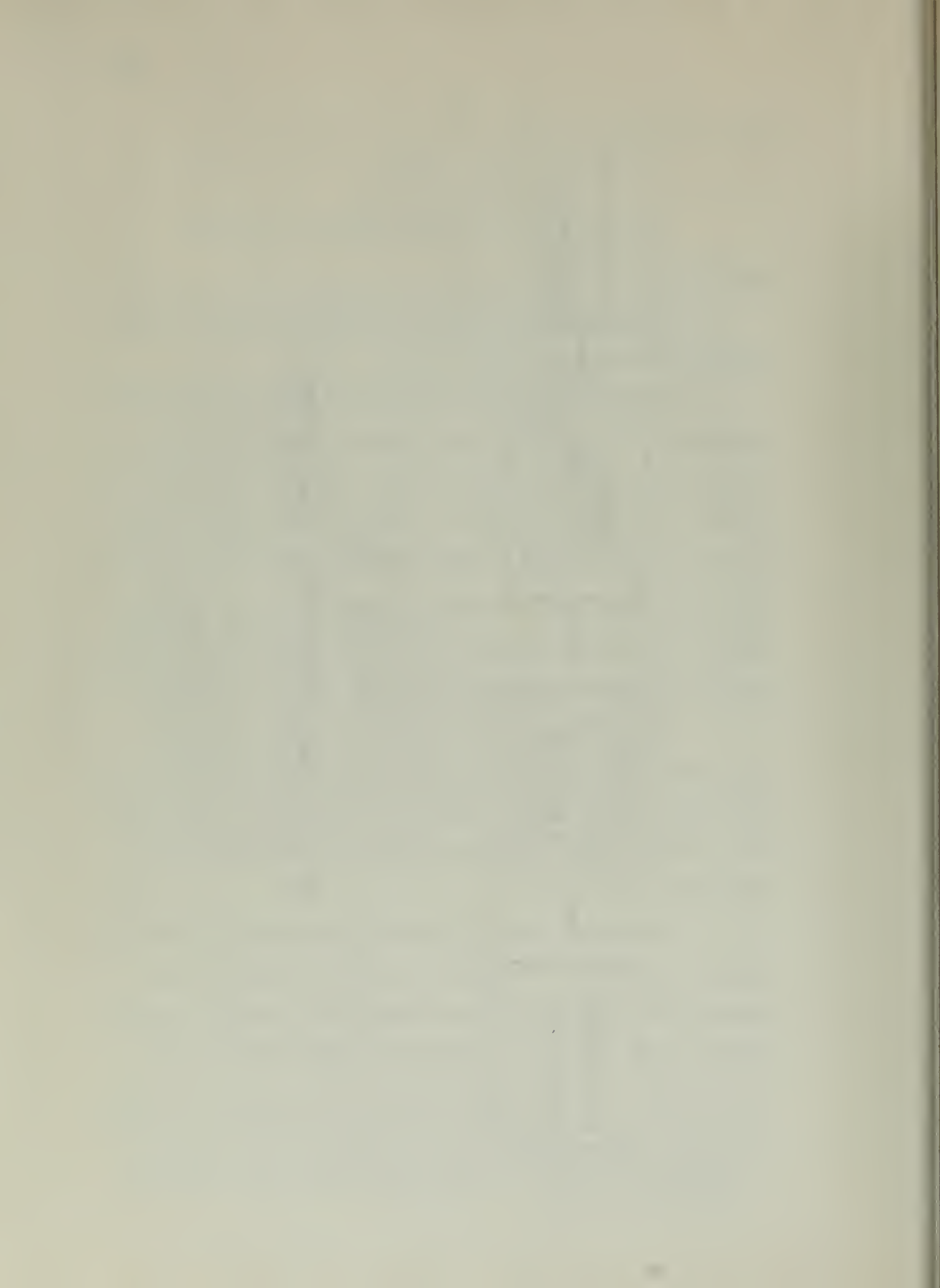


FIGURE 6.  
BLOCK DIAGRAM OF TEST EQUIPMENT





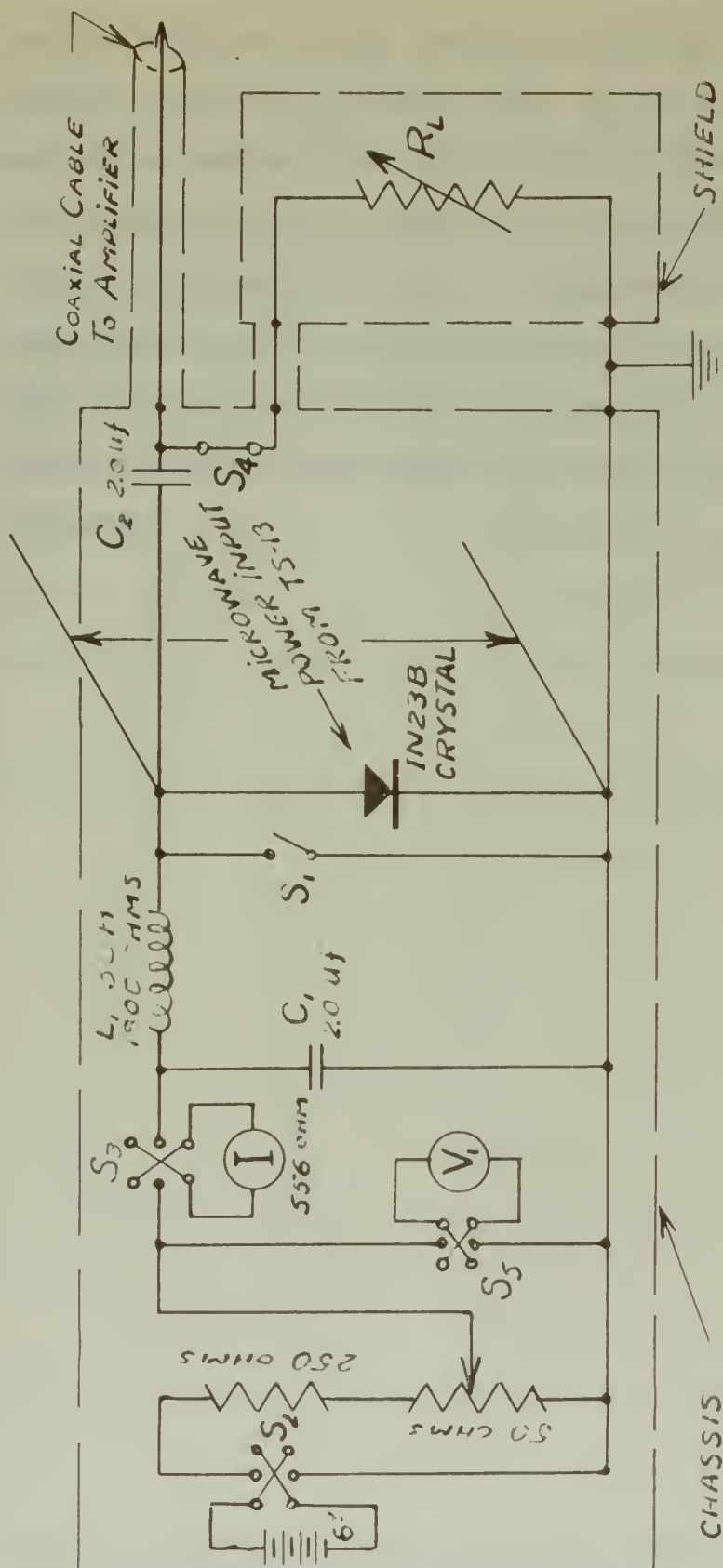
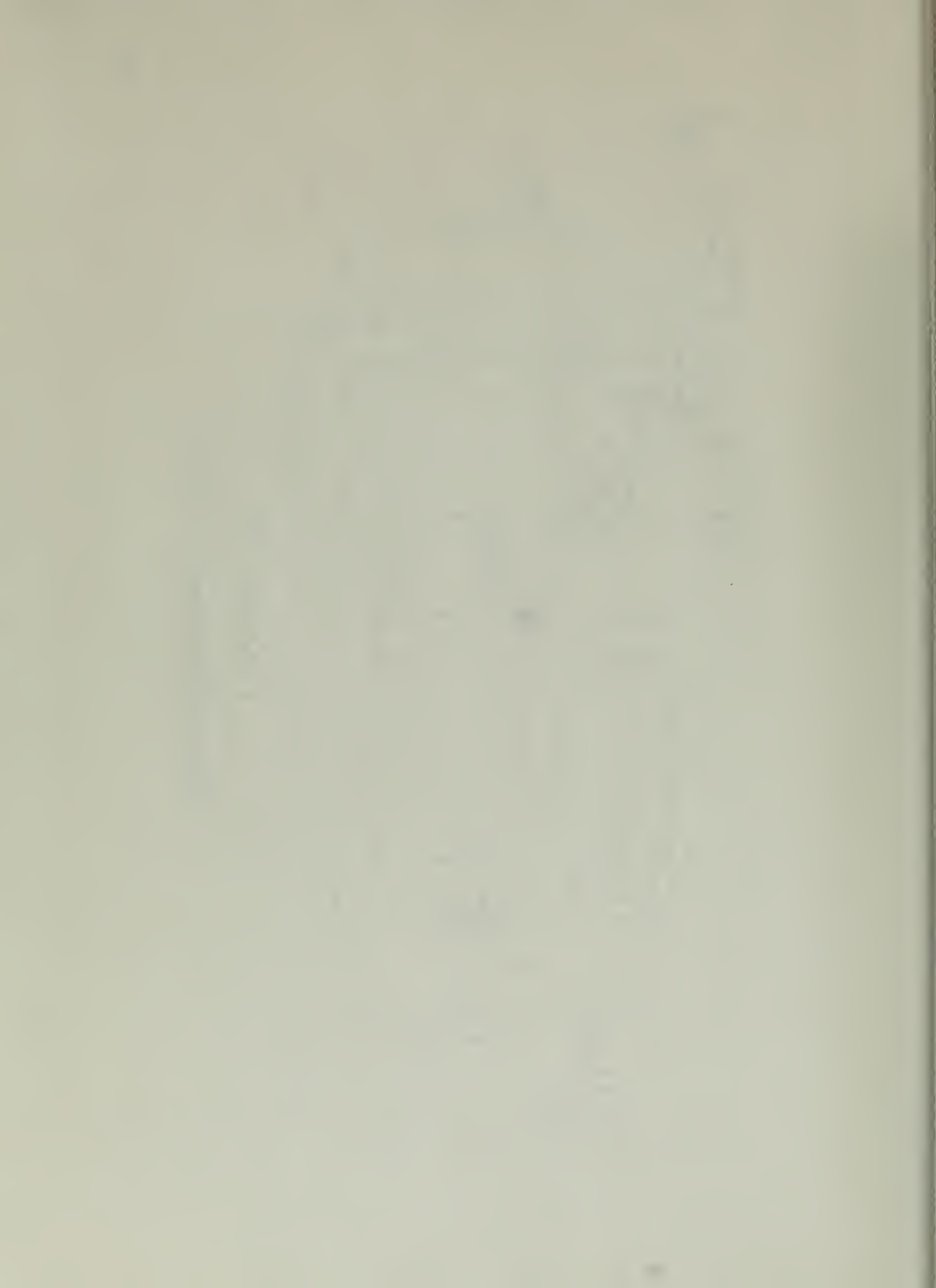


FIGURE 7.  
BIASING AND LOADING CIRCUIT



The load resistance  $R_L$  had a built-in shield and was connected to the metal chassis by a coaxial cable.  $R_L$  was a non-inductively wound decade resistance box with a maximum resistance of 100,000 ohms. The microwave power was carried from the TS-13/AP by means of standard 3 cm. band waveguide to a variable-tuned 3 cm band crystal holder mounted on the side of the biasing circuit chassis. The output terminal of the crystal holder was inside the chassis. The effective microwave input terminals are shown by the diagonal lines in Figure 6.

---

\* For detailed drawing of crystal holder see page 353 of (2).



The first condition of the law is that the person who is  
 the subject of the law must be a citizen of the United States.  
 The second condition is that the person must be a resident of the  
 United States at the time of the law's enactment. The third  
 condition is that the person must be a resident of the United States  
 at the time of the law's enactment. The fourth condition is that  
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 The seventh condition is that the person must be a resident of  
 the United States at the time of the law's enactment. The eighth  
 condition is that the person must be a resident of the United States  
 at the time of the law's enactment. The ninth condition is that  
 the person must be a resident of the United States at the time of  
 the law's enactment. The tenth condition is that the person must  
 be a resident of the United States at the time of the law's  
 enactment.

#### IV

#### TEST PROCEDURE AND RESULTS

Since it is possible to represent the video crystal as a voltage generator with an internal resistance, it is apparent that maximum power transfer to the load resistance will occur when  $R_x$  equals  $R_L$  provided  $E_x$  remains constant. The determination of the variation of  $R_x$  with power level and bias is based on this maximum power transfer principle. Five crystals were chosen at random from the available supply so that a measure of the variation to be expected from crystal to crystal could be determined\*. All crystals were of Sylvania design and manufacture.

##### Variation of Crystal Resistance With Microwave Power Level

The first experiment was designed to determine the variation of  $R_x$  with variation in the microwave power input to the crystal. A bias current of 10 microamperes was put through the crystal and the load varied for a constant input power of 30dbm (decibels below a milliwatt). The output voltage shown on the Hewlett-Packard voltmeter was recorded. The above procedure was repeated for input power levels of 40dbm and 45dbm. The results of all three power levels are plotted in Figure 7.

To determine  $R_x$  it is necessary to find that value of  $R_L$  which makes the power transferred to the load a maximum. This is done by determining the point at which a line of constant power

---

\* For identification purposes the crystals used were assigned numbers. These numbers appear on the curves throughout the paper.

ARTICLE BY J. H. HARRIS, M.D.

THE AMERICAN MEDICAL ASSOCIATION'S POSITION ON THE QUESTION OF THE

PROHIBITION OF THE SALE OF DRUGS TO THE PUBLIC AT WHOLESALE PRICES

AND THE PROHIBITION OF THE SALE OF DRUGS TO THE PUBLIC AT RETAIL PRICES

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is tangent to the desired curve. The point of tangency will be at that value of  $R_L$  for which the power in the load is a maximum. A line of constant power is shown in the figure for reference. The vertical marks on each curve show the points of tangency.  $R_L$  at this point is equal to  $R_X$  for the bias current used in the experiment.

From Figure 8 it is seen that the variation of crystal resistance is negligible for power input between 0.03 and 1.0 microwatts (45dbm and 30dbm). The remainder of the experiments have been conducted at the 40dbm level and the results are considered valid for the entire microwatt region (50dbm to 20dbm).

#### Variation of Crystal Resistance With Bias

The curves of Figures 9, 10 and 11 were obtained for bias currents of 0.0, 5.0 and 10.0 microamperes respectively by varying the crystal load resistance and recording the output voltage as read on the Hewlett-Packard voltmeter at constant power input. By determining the point of tangency of the line of constant power, we can as before get the value of  $R_X$ . The points of tangency are indicated by short vertical lines on the curves. The value of  $R_X$  is shown by vertical lines near the bottom of the Figures, the value being read on the  $R_L$  scale.

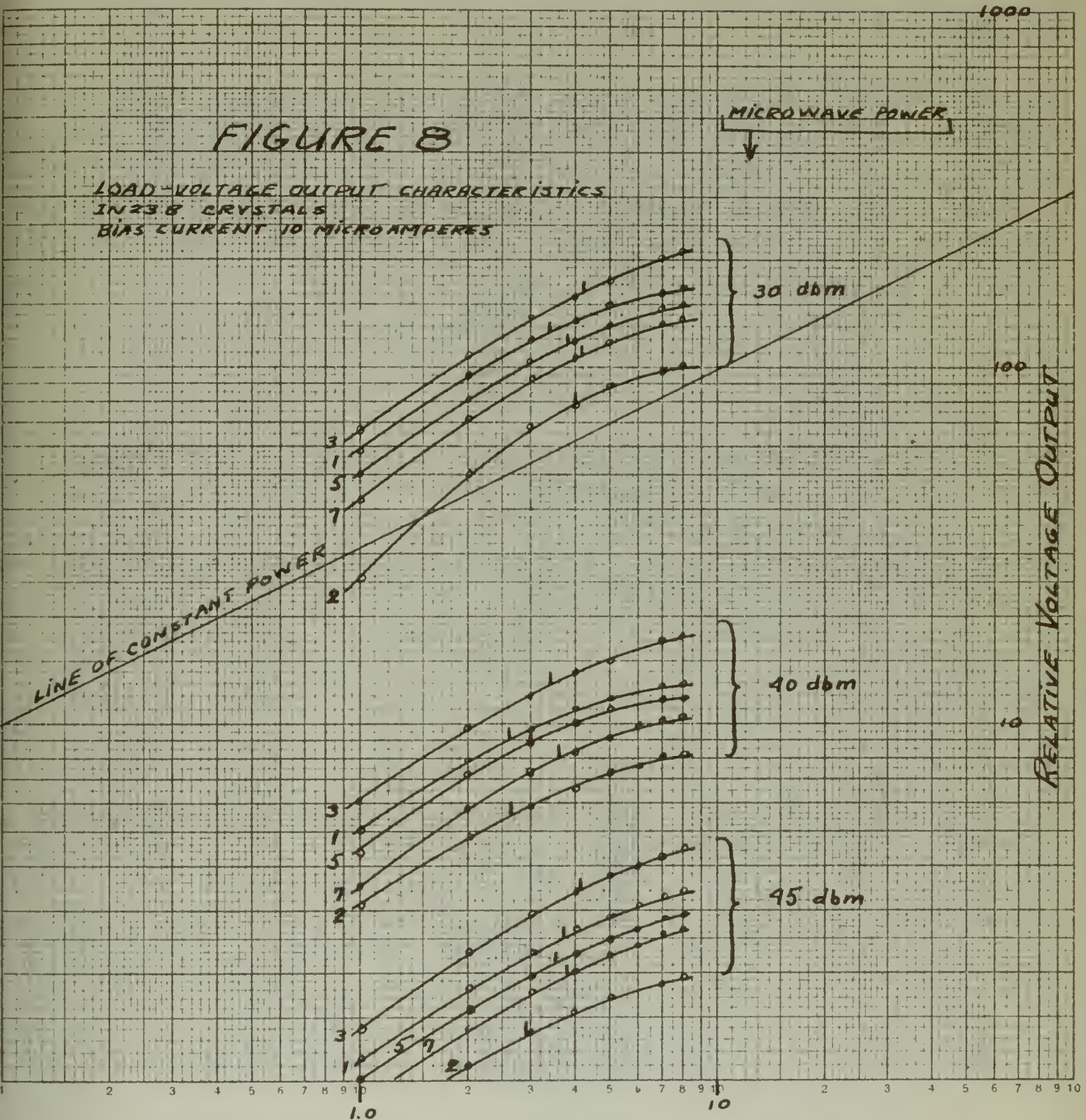
A second means of determining crystal resistance-bias characteristics is the halving method. If the open circuited voltage of Figure 5 is known and  $R_L$  is adjusted to give an output voltage of one half the open circuited voltage, application of Thevenin's Theorem shows that  $R_L$  is equal to  $R_X$ . Computations show that the maximum expected error in determination of  $R_X$  by





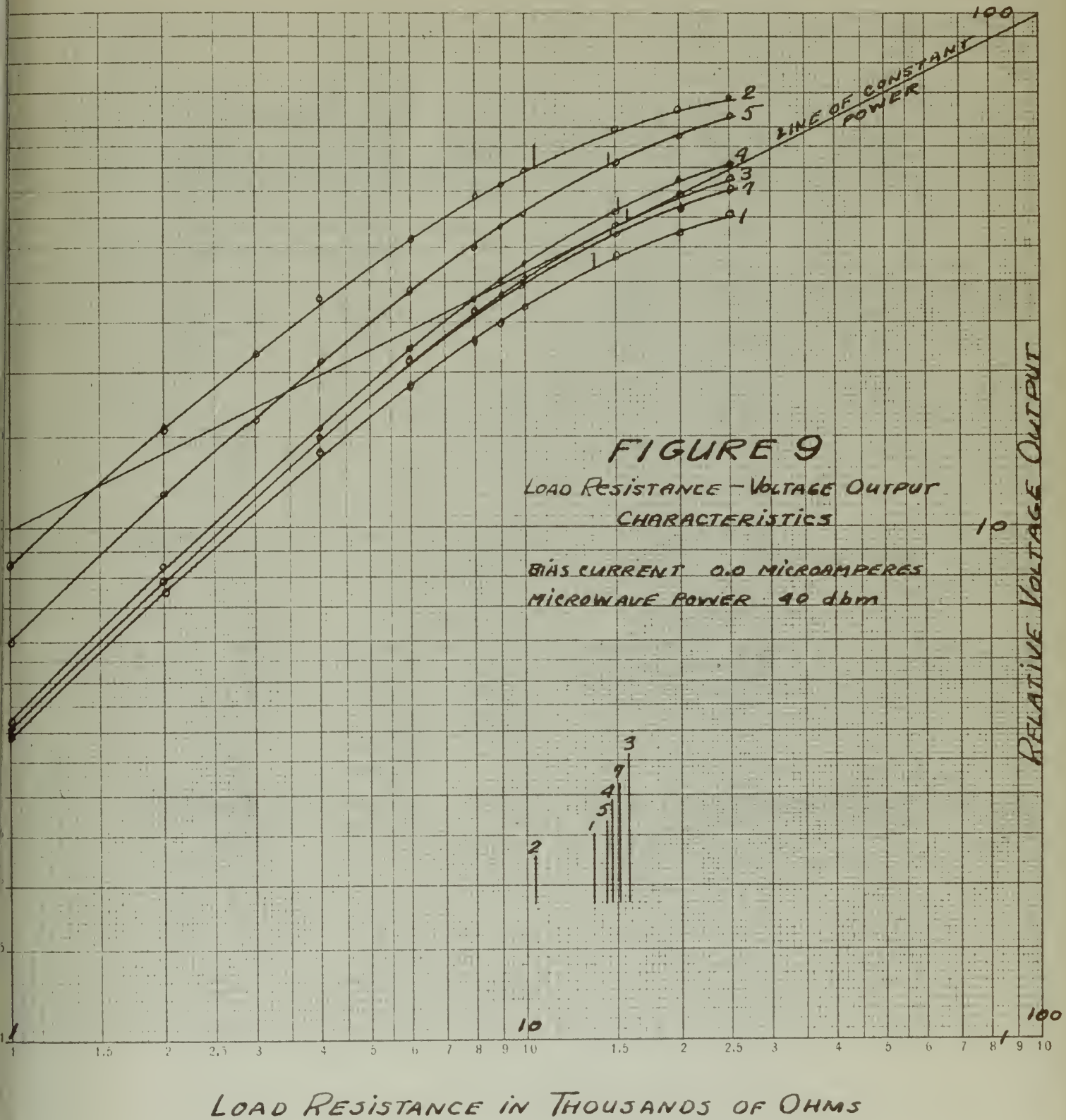
FIGURE 8

LOAD-VOLTAGE OUTPUT CHARACTERISTICS  
IN 23.8 CRYSTALS  
BIAS CURRENT 10 MICROAMPERES



LOAD RESISTANCE IN THOUSANDS OF OHMS





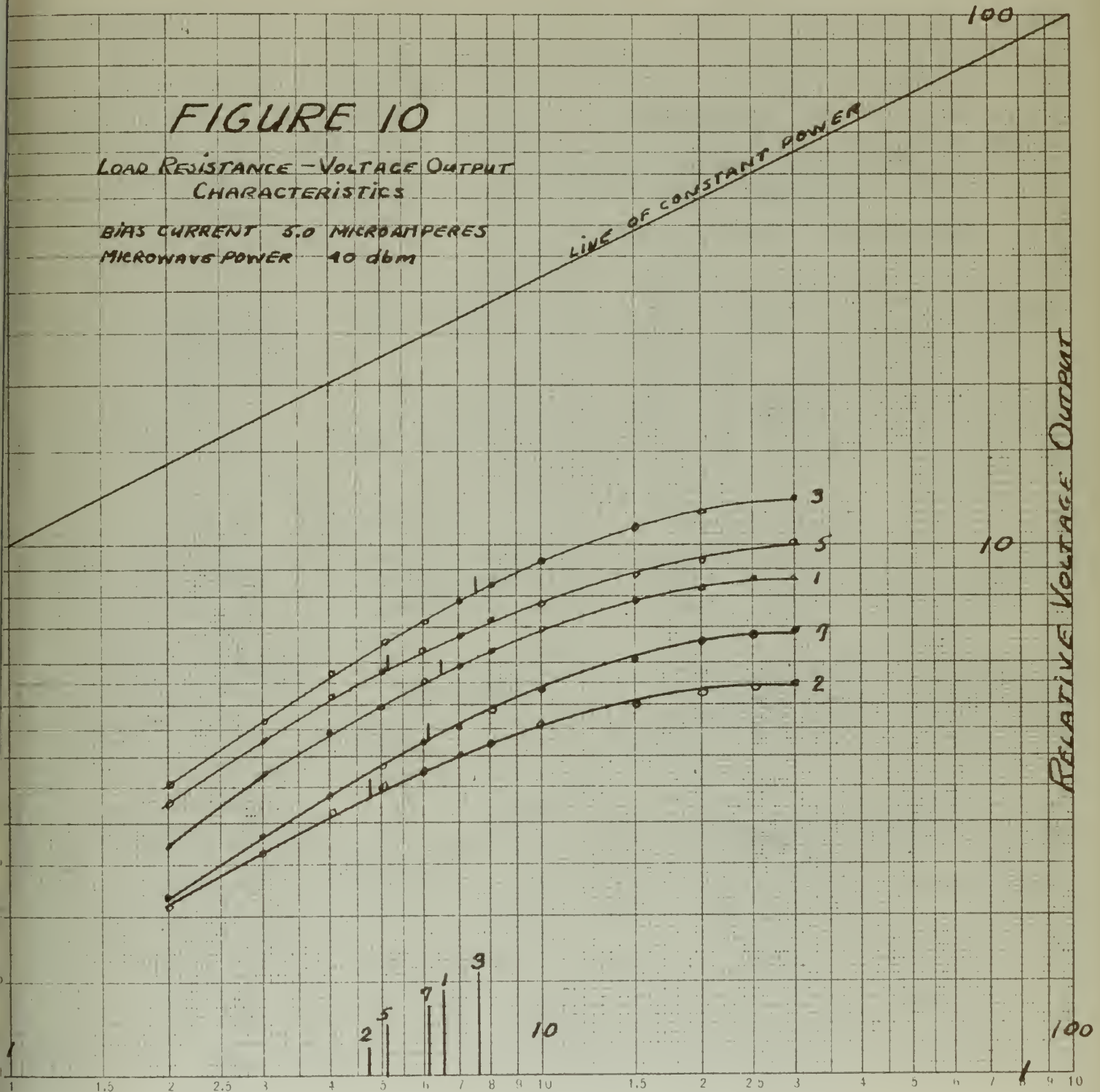




# FIGURE 10

LOAD RESISTANCE - VOLTAGE OUTPUT  
CHARACTERISTICS

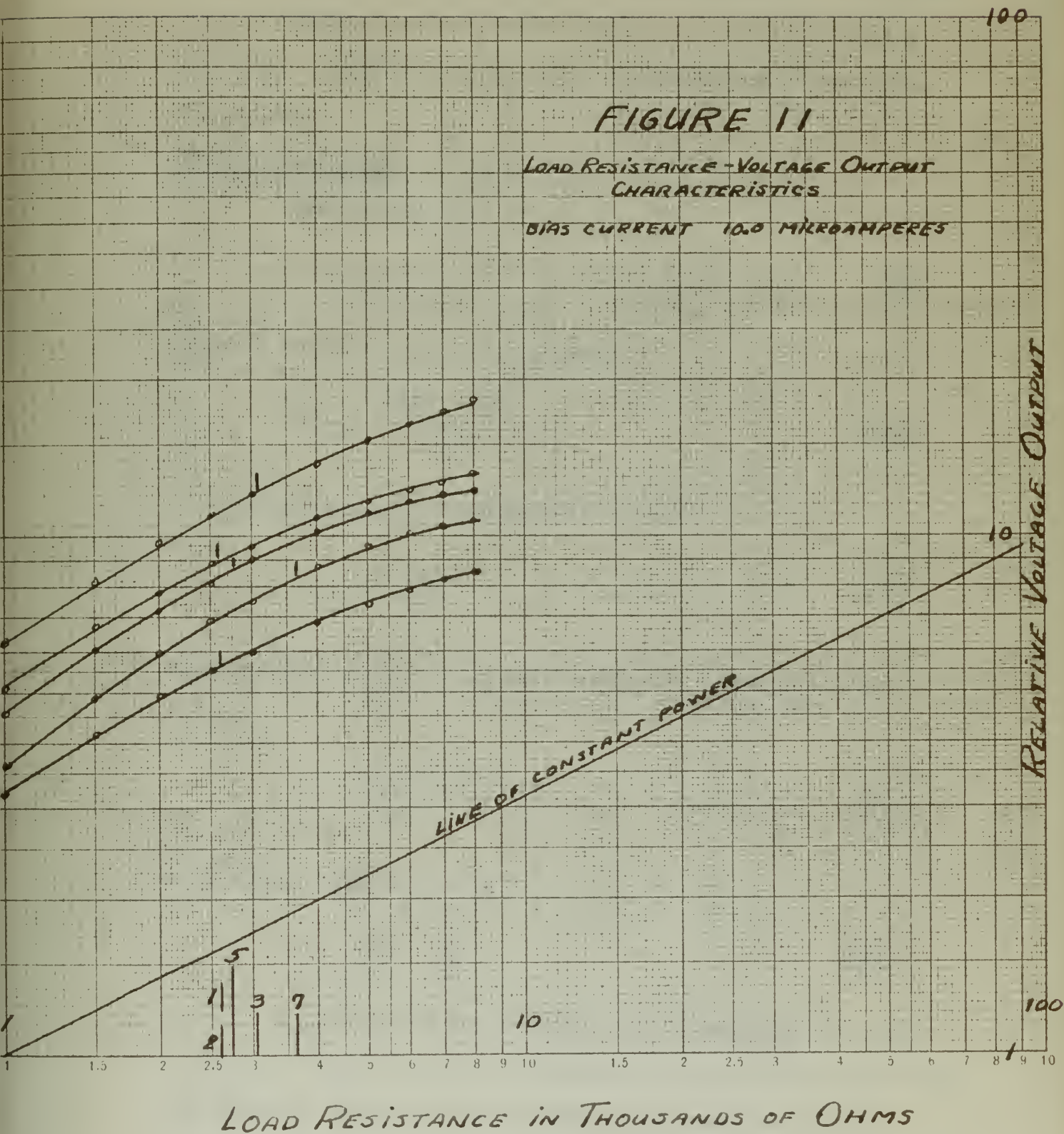
BIAS CURRENT 5.0 MICROAMPERES  
MICROWAVE POWER 10 dbm



LOAD RESISTANCE IN THOUSANDS OF OHMS









This halving method is 3 percent and is due to the input resistance of the amplifier not being infinity, but 500,000 ohms. The results of this procedure are tabulated in Table I. Using this data the curves for crystals number 3 and 5 were plotted and are shown in Figure 12.

### Current Sensitivity

From Equation 4,

$$i_s = \beta P \quad (9)$$

Referring to Figure 5, it is seen that,

$$E_x = \frac{(R_x + R_L)}{R_L} V_L \quad (10)$$

If  $R_L$  is set equal to zero in Figure 5, then,

$$i_s = \frac{E_x}{R_L} \quad (11)$$

Equating Equations 9 and 11, and substituting Equation 10 for  $E_x$  gives,

$$\beta = \frac{(R_x + R_L)}{R_x R_L P} V_L \quad (12)$$

If  $R_L$  is set equal to  $R_x$ , then

$$\beta = \left(\frac{2}{P}\right) \cdot \frac{V_L}{R_L} \quad (13)$$

$V_L$  and  $R_L$ , for the condition that  $R_L$  equal  $R_x$ , are given in Table I. Using this data and Equation 13, the curves in Figure 13 were plotted. Since  $R_x$  is not a function of power level in the microwatt region the constant  $\left(\frac{2}{P}\right)$  acts only as a linear scale factor for the curves.

This is the first of the three conditions  
 in the definition of a group. The second  
 is that the operation is associative. The third  
 is that there is an identity element \$e\$ such that  
 \$e \cdot x = x\$ and \$x \cdot e = x\$ for all \$x\$ in the group.

Example 1.1

Let \$G\$ be the set of

$$G = \{1, 2, 3, 4, 5, 6\}$$

under the operation of addition modulo 6.

$$(1) \quad 1 + 5 = 6 \equiv 0 \pmod{6}$$

It is not true that \$1 + 5 \equiv 0 \pmod{6}\$.

$$(2) \quad 1 + 1 = 2 \pmod{6}$$

Therefore \$1\$ and \$5\$ are not inverses in \$G\$.

$$(3) \quad 1 + 1 = 2 \pmod{6}$$

It is not true that \$1 + 1 \equiv 0 \pmod{6}\$.

$$(4) \quad 1 + 1 = 2 \pmod{6}$$

It is not true that \$1 + 1 \equiv 0 \pmod{6}\$.  
 In fact, \$1 + 1 \equiv 2 \pmod{6}\$. The reason is that  
 \$1 + 1 = 2\$, and \$2 \equiv 2 \pmod{6}\$.  
 Therefore \$1\$ and \$1\$ are not inverses in \$G\$.  
 (5)



# TABLE I

## CRYSTAL RESISTANCE

	CRYSTAL No. 1		CRYSTAL No. 2		CRYSTAL No. 3		CRYSTAL No. 5		CRYSTAL No. 7	
I	$E_L$	$R_x$	$E_L$	$R_x$	$E_L$	$R_x$	$E_L$	$R_x$	$E_L$	$R_x$
0.0	5.40	10.0	4.60	9.30	3.25	11.1	5.25	10.8	3.90	11.6
2.5	9.75	4.80	5.25	5.30	11.0	8.00	8.50	6.20	8.00	7.00
5.0	9.75	3.56	5.25	3.95	11.2	5.50	8.40	4.20	8.00	4.70
7.5	9.50	3.25	5.20	3.14	10.8	4.40	8.10	3.20	7.70	3.54
10.0	9.10	2.60	5.10	2.54	10.5	3.20	7.50	2.40	7.40	2.87
20.0	7.70	1.41	4.65	2.27	9.20	1.65	6.50	1.45	6.20	1.64
30.0	6.60	.94	4.25	1.05	7.50	1.10	5.70	.99	5.40	1.17
40.0	6.00	.78	3.92	.82	6.70	.93	5.10	.86	5.00	1.03
50.0	5.30	.64	3.70	.70	5.80	.75	4.60	.73	4.55	.83
60.0	5.00	.59	3.45	.58	5.20	.66	4.15	.63	4.10	.71
70.0	4.55	.53	3.20	.51	4.60	.58	3.70	.55	3.70	.62
80.0	4.10	.46	3.10	.49	4.30	.57	3.35	.48	3.35	.55
90.0	3.80	.43	2.85	.42	3.90	.52	3.10	.44	3.10	.51
100.0	3.60	.41	2.70	.40	3.70	.50	3.00	.43	2.90	.49

$I$  = BIAS CURRENT IN MICROAMPERES

$R_x = R_L$  = CRYSTAL LOAD RESISTANCE AT  $E_L = \frac{1}{2} E_{\text{OPEN CIRCUIT}}$

第 一 章

緒 論

一、研究之目的及意義

二、研究之範圍及對象

三、研究之方法

四、研究之步驟

五、研究之結論

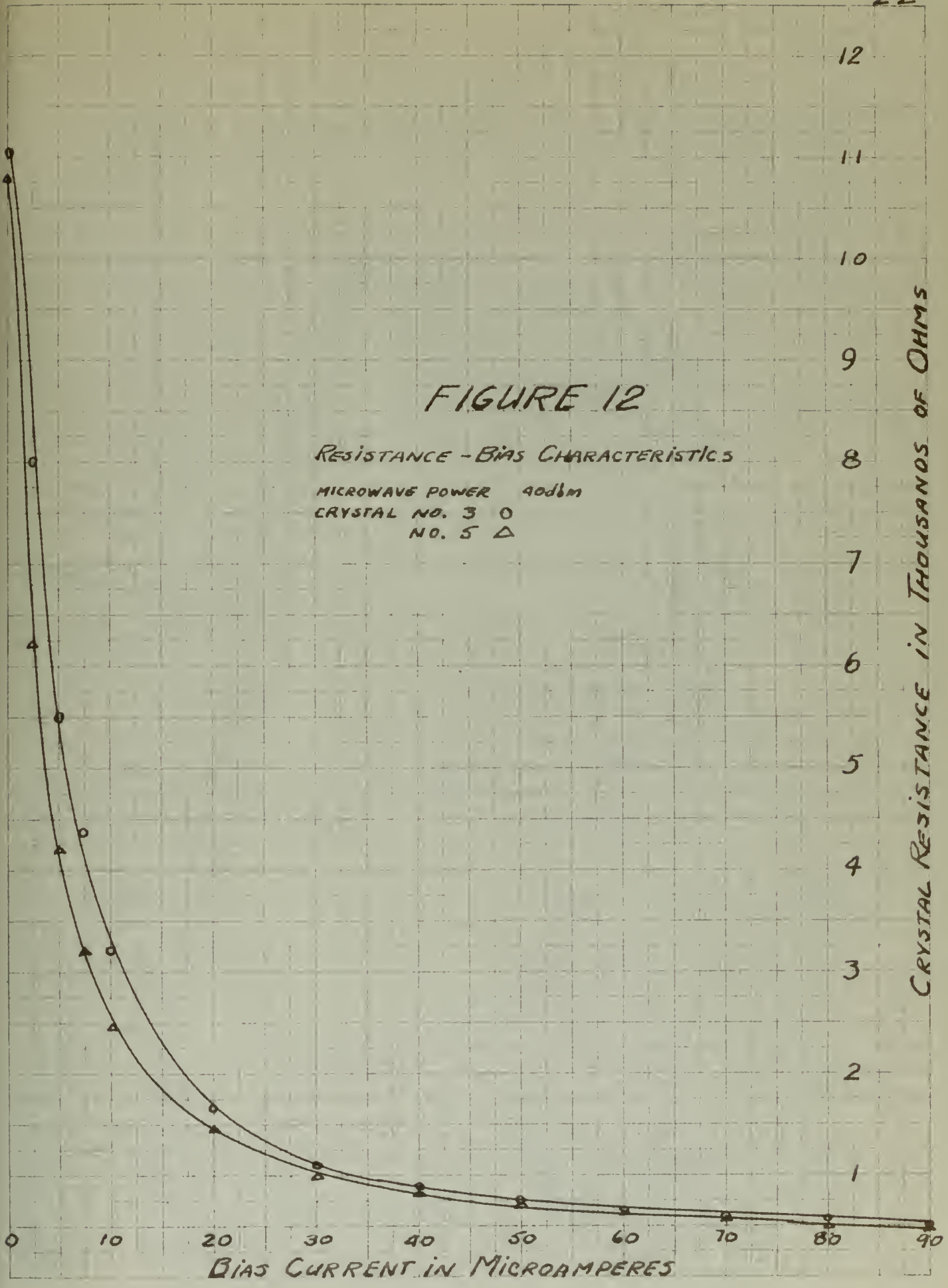
六、研究之貢獻

七、研究之限制

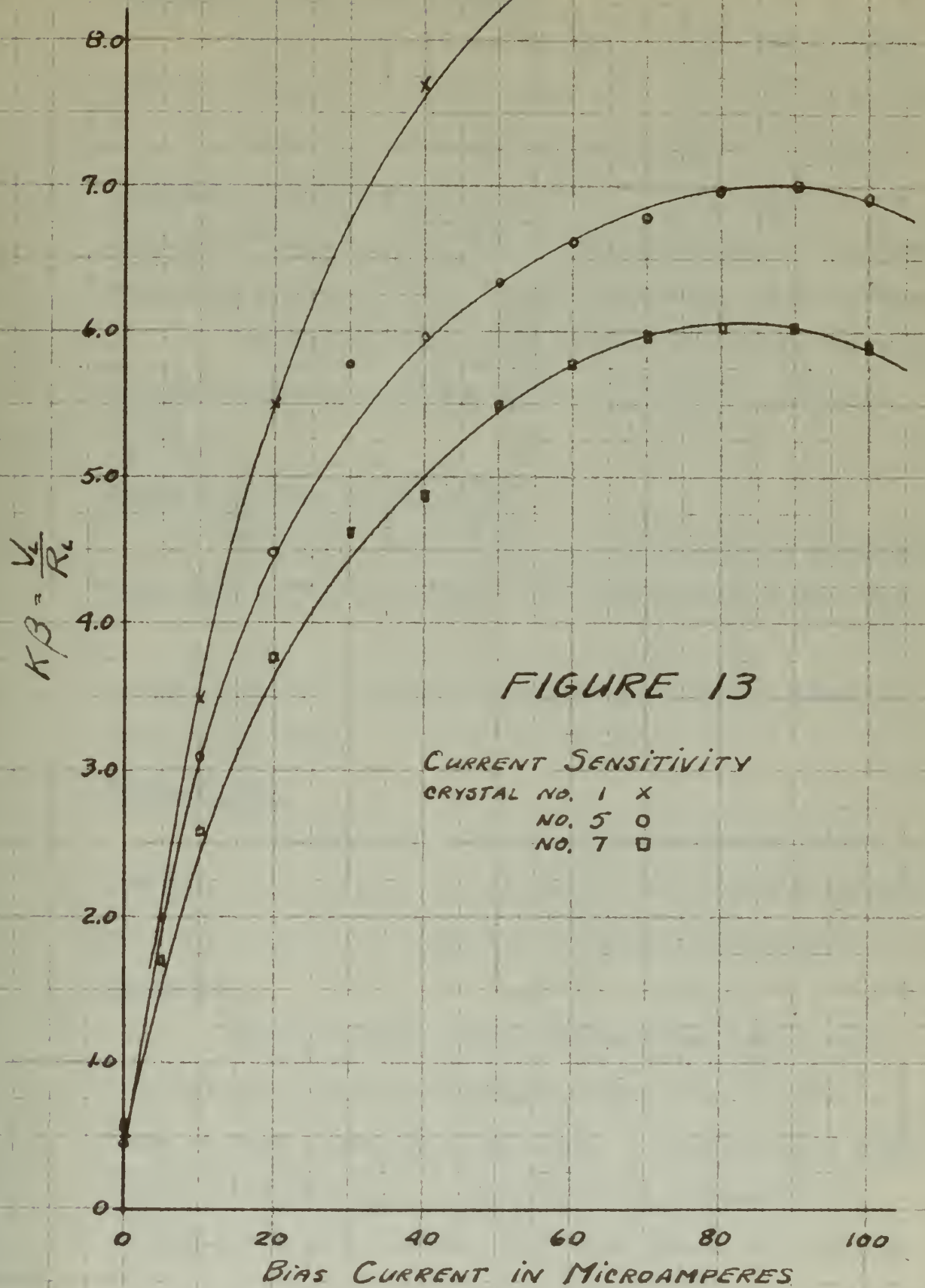
八、研究之展望

九、研究之參考文獻

十、研究之附錄











### Variation of Crystal Output Voltage

Crystal output voltage was investigated in three manners:

- 1) by the variation of the bias current with the load as a parameter,
  - 2) by the variation of bias with the power input to the crystal as a parameter, the load being kept constant at 2,000 ohms, 3) by the variation of the power input with the bias being taken as a parameter.
- The results of these tests are shown in Figures 14, 15, 16 and 17.

Variation of crystal output voltage for different crystals was determined as a function of bias. The results are shown in Figure 18.

### Variation of Crystal Power Output

The data given in Table I is for the condition of maximum power transfer from the crystal to the load. From this data  $\frac{(E_o)^2}{R_L}$  was calculated and the resulting maximum power transfer curve is shown in Figure 19.

### Figure of Merit

Two methods were used to determine the variation of  $M$  with bias. The first was by substituting into Equation 7, the data available in Table I and Figure 13. The results are given in Figure 20.

The second method was by experimentation based on the fact that for a given signal-to-noise voltage output ratio the Figure of Merit is inversely proportional to the power input to the crystal (See Equation 8). To determine  $M$  the bias current was adjusted to the desired value and the power output of the TS-13AP

# Definition of Special Topics

Special topics are defined as follows:

- (1) The first of the two topics is the first of a sequence.
- (2) The second of the two topics is the second of a sequence.
- (3) The third of the two topics is the third of a sequence.
- (4) The fourth of the two topics is the fourth of a sequence.
- (5) The fifth of the two topics is the fifth of a sequence.
- (6) The sixth of the two topics is the sixth of a sequence.
- (7) The seventh of the two topics is the seventh of a sequence.
- (8) The eighth of the two topics is the eighth of a sequence.
- (9) The ninth of the two topics is the ninth of a sequence.
- (10) The tenth of the two topics is the tenth of a sequence.

The first of the two topics is the first of a sequence.

The second of the two topics is the second of a sequence.

## Definition of Special Topics

The first of the two topics is the first of a sequence.

The second of the two topics is the second of a sequence.

The third of the two topics is the third of a sequence.

The fourth of the two topics is the fourth of a sequence.

The fifth of the two topics is the fifth of a sequence.

## Definition of Special Topics

The first of the two topics is the first of a sequence.

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The fourth of the two topics is the fourth of a sequence.

The fifth of the two topics is the fifth of a sequence.

The sixth of the two topics is the sixth of a sequence.

The seventh of the two topics is the seventh of a sequence.

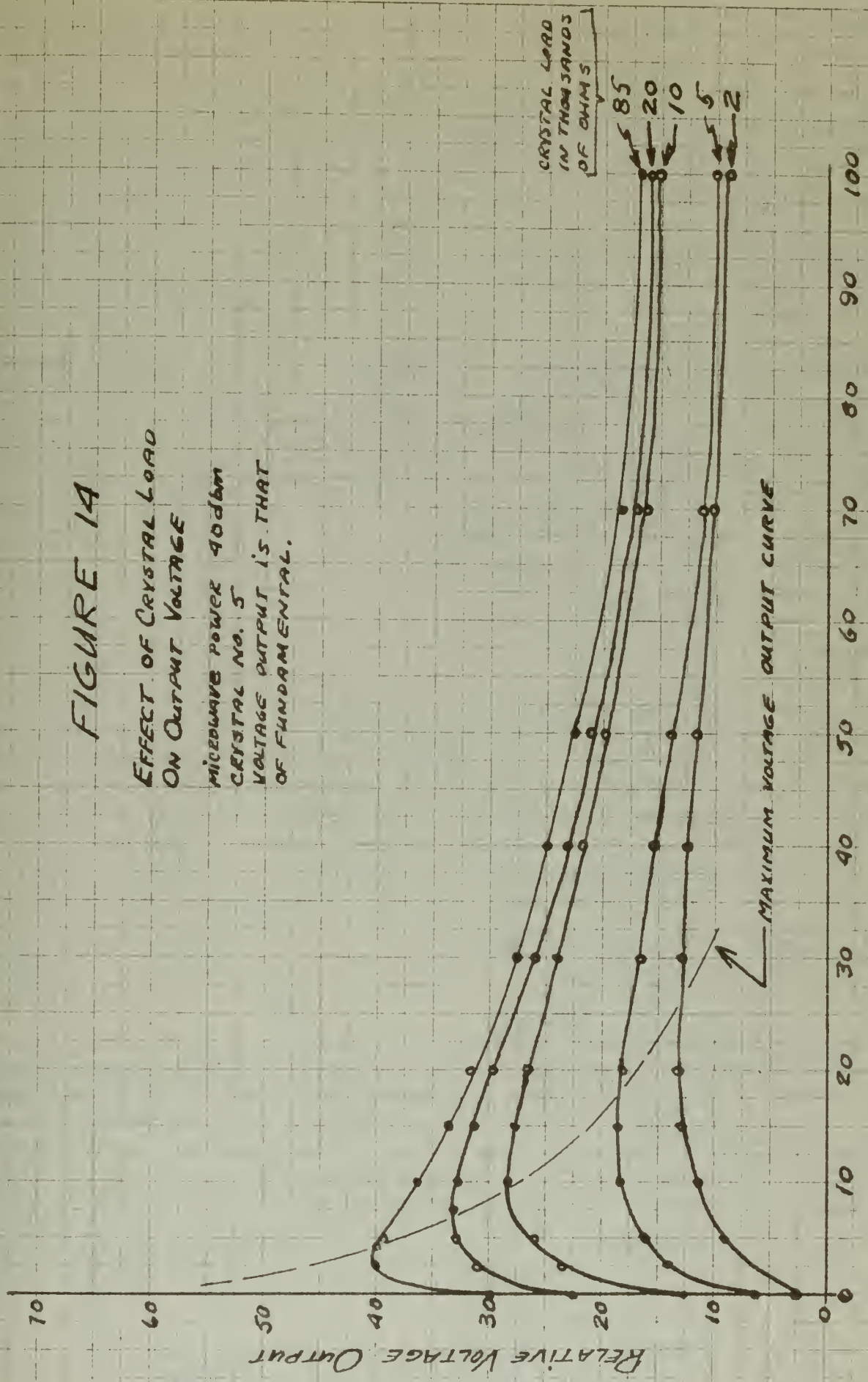
The eighth of the two topics is the eighth of a sequence.

The ninth of the two topics is the ninth of a sequence.

FIGURE 14

EFFECT OF CRYSTAL LOAD  
ON OUTPUT VOLTAGE

MICROWAVE POWER 40dbm  
CRYSTAL NO. 5  
VOLTAGE OUTPUT IS THAT  
OF FUNDAMENTAL.



BIAS CURRENT IN MICROAMPERES

MAXIMUM VOLTAGE OUTPUT CURVE

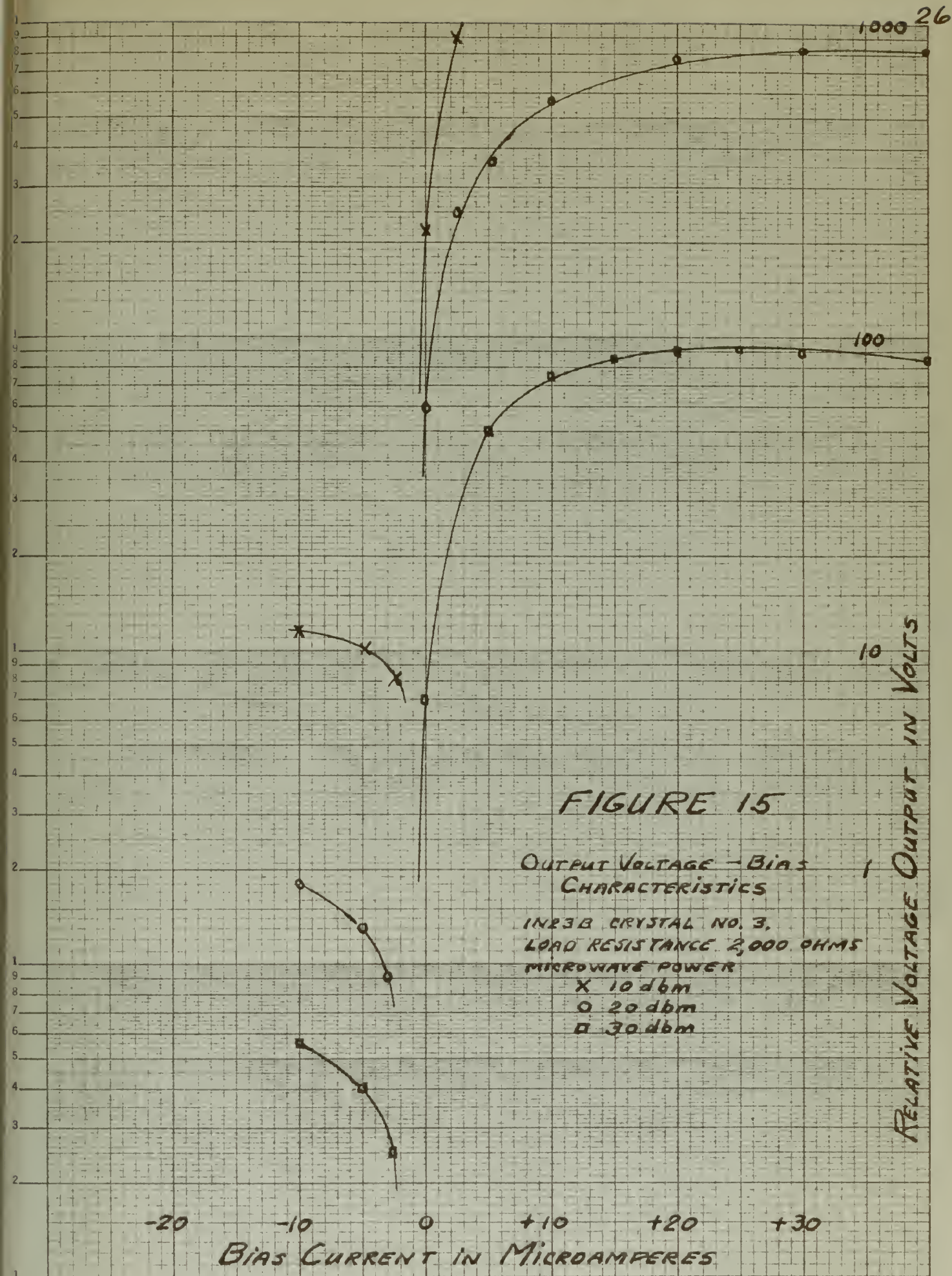
CRYSTAL LOAD  
IN THOUSANDS  
OF OHMS

85  
20  
10  
5  
2



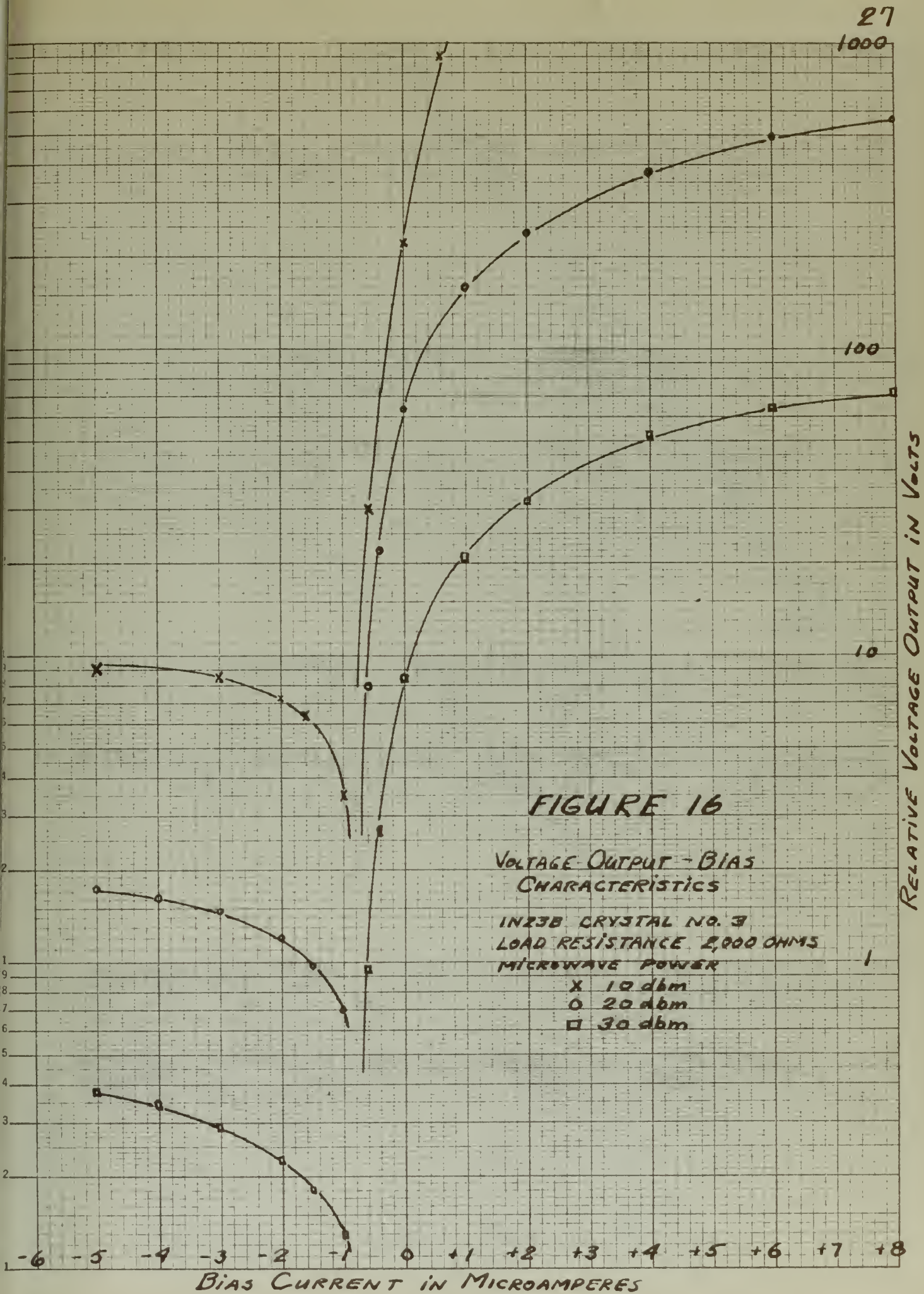
















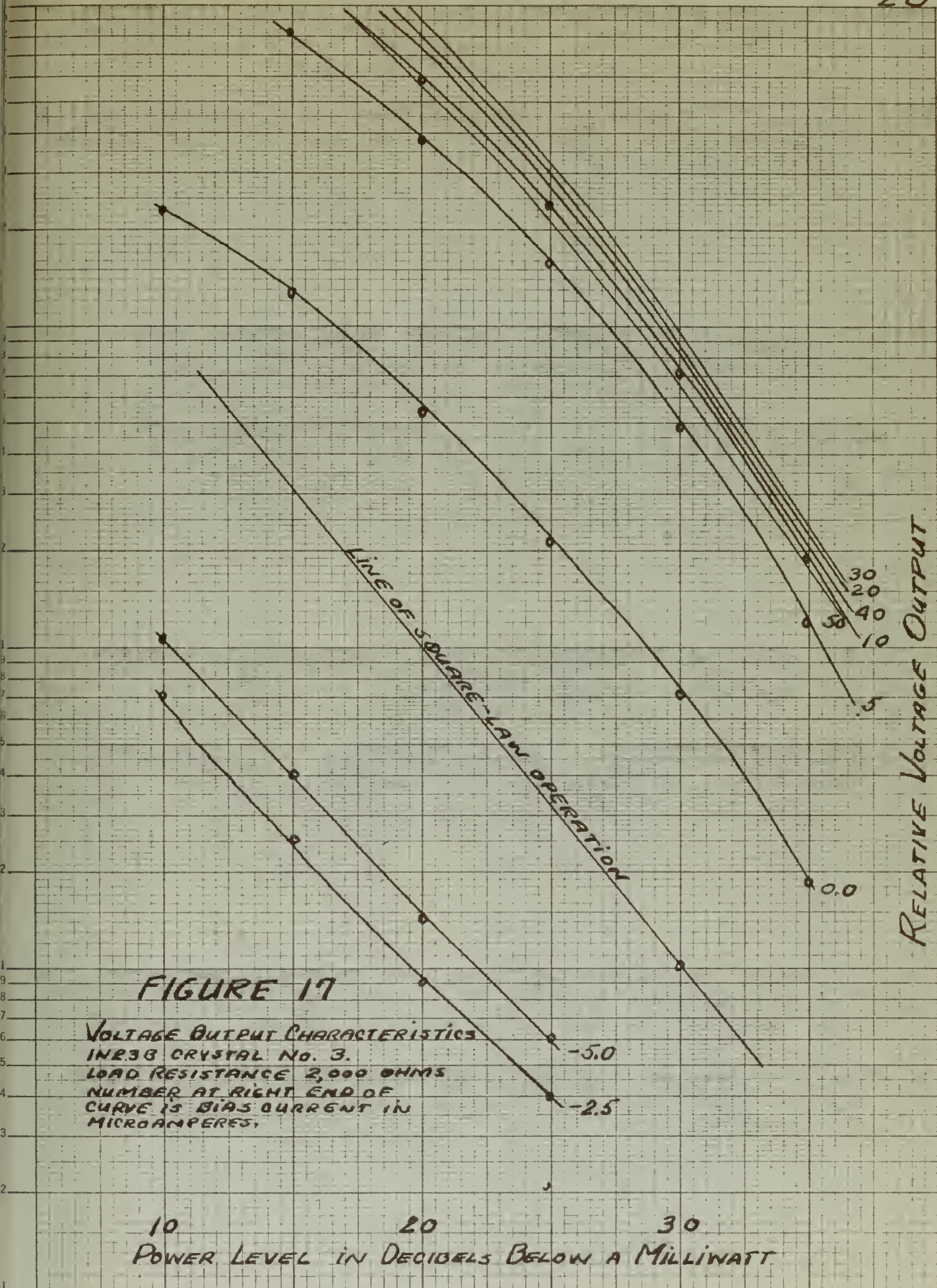


FIGURE 17

VOLTAGE OUTPUT CHARACTERISTICS  
 IN23B CRYSTAL NO. 3.  
 LOAD RESISTANCE 2,000 OHMS  
 NUMBER AT RIGHT END OF  
 CURVE IS BIAS CURRENT IN  
 MICROAMPERES.

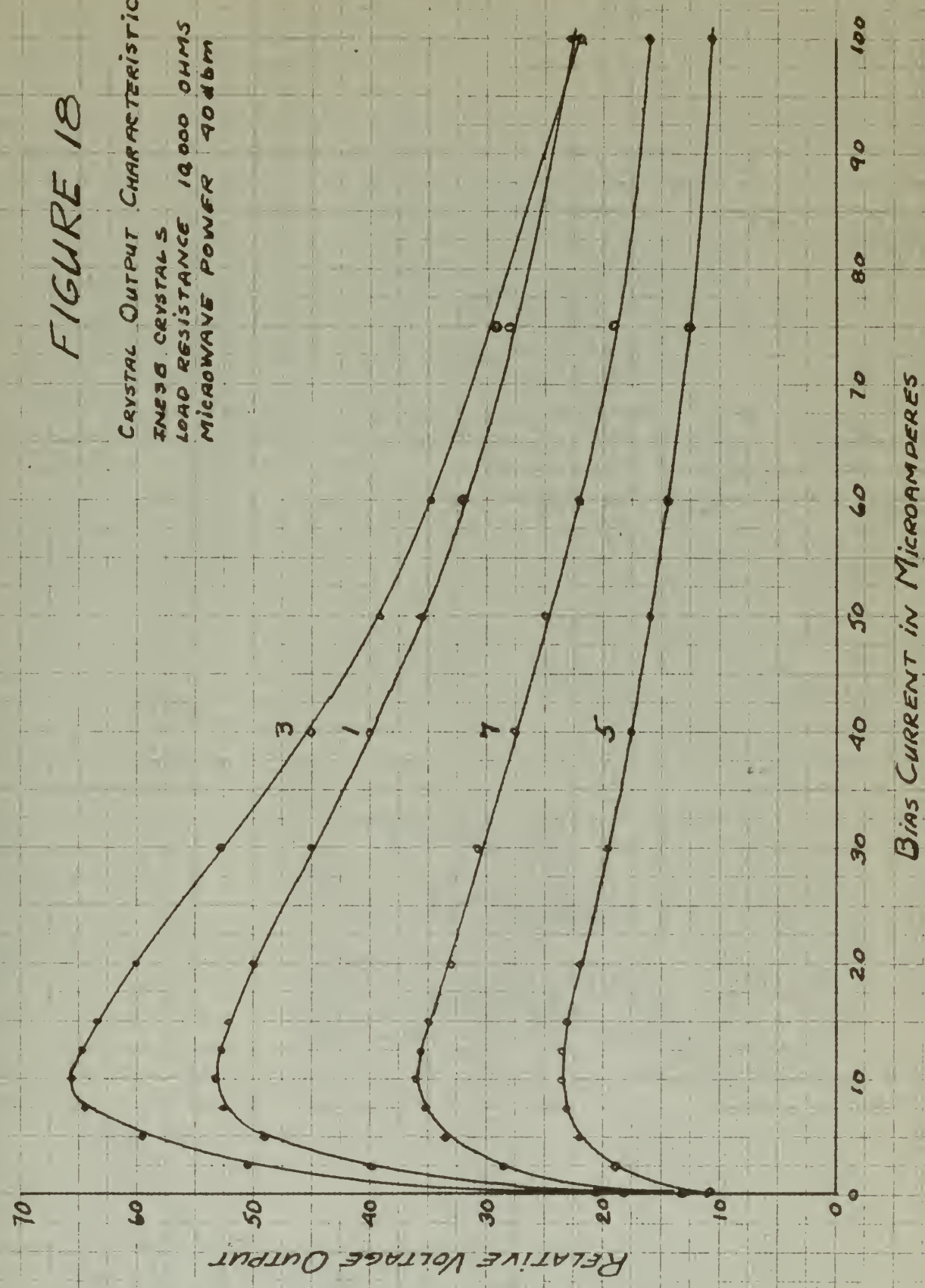
10                      20                      30  
 POWER LEVEL IN DECIBELS BELOW A MILLIWATT





FIGURE 18

CRYSTAL OUTPUT CHARACTERISTICS  
7ME3B CRYSTALS  
LOAD RESISTANCE 10000 OHMS  
MICROWAVE POWER 40dbm





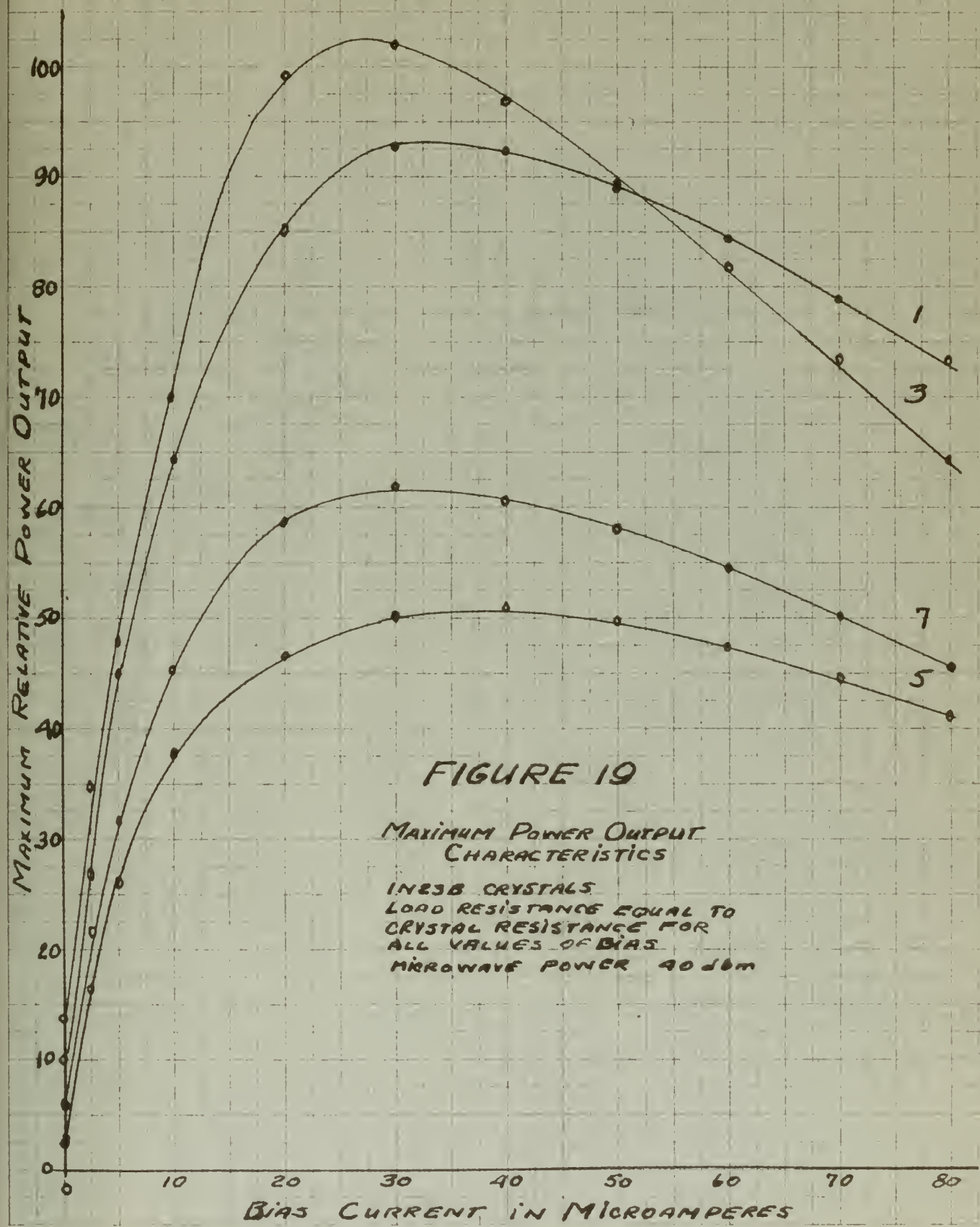
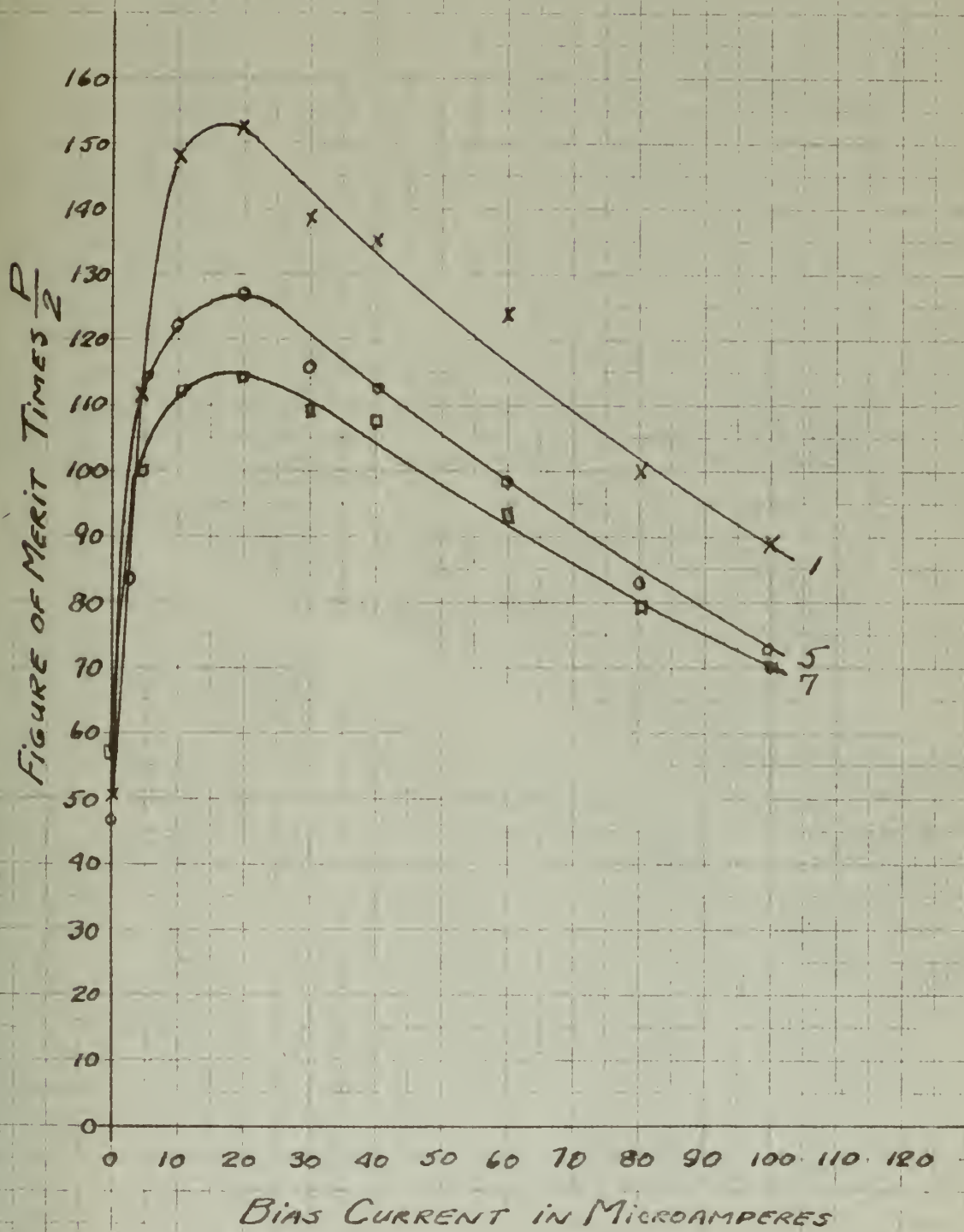






FIGURE 20

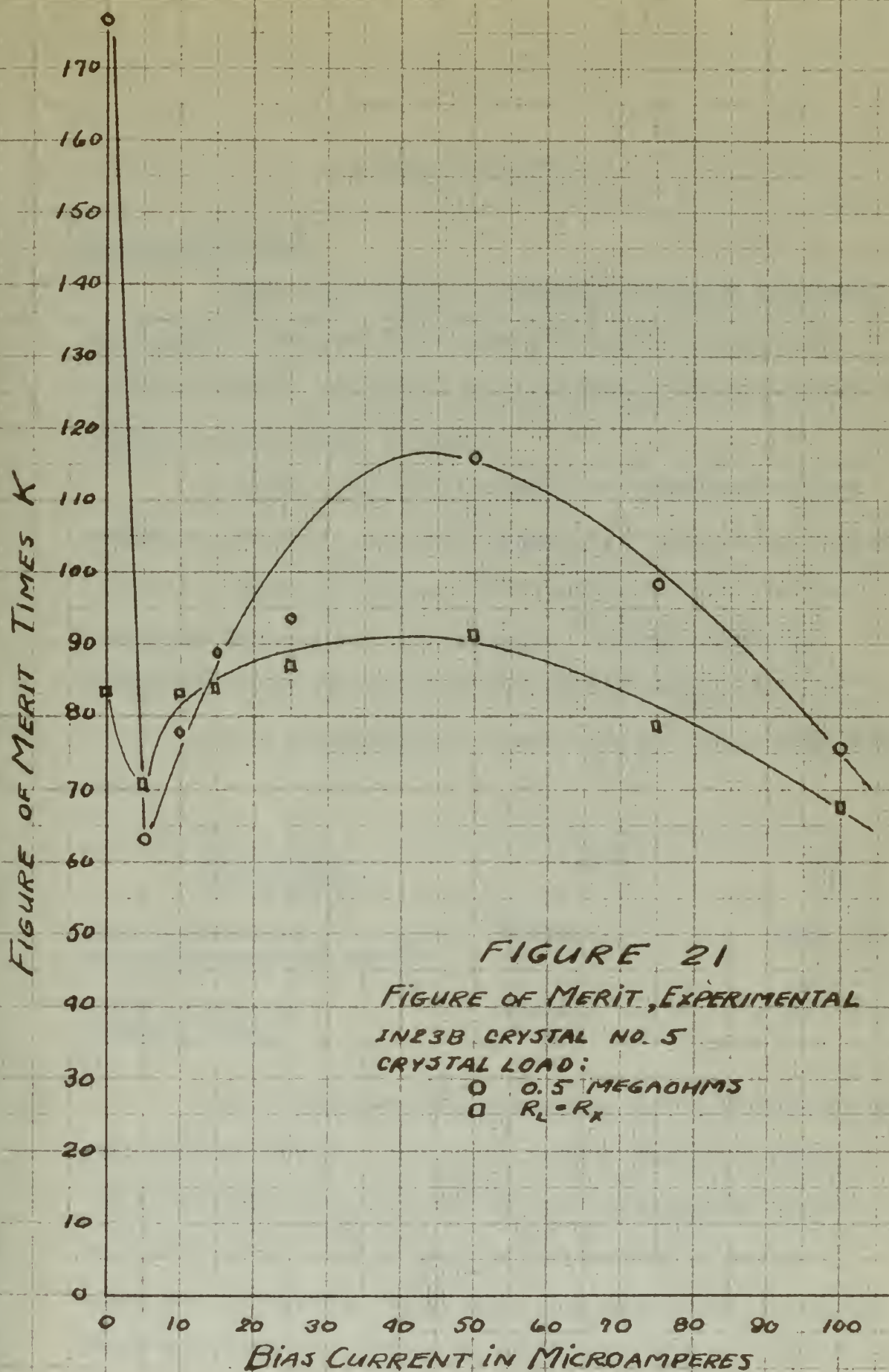
FIGURE OF MERIT  
IN 238 CRYSTALS





decreased until a signal-to-noise voltage output ratio of 1 was observed on the oscilloscope. The inverse of this power is  $KW$ . The procedure was repeated for bias currents from zero to 100.0 microamperes. The results are plotted in Figure 21.

1. The above information is for informational purposes only and is not intended to be used for any other purpose. The information is provided for your information only and is not intended to be used for any other purpose. The information is provided for your information only and is not intended to be used for any other purpose.







## ANALYSIS OF RESULTS

Crystal Resistance

Figure 8 shows that the variation of crystal resistance is negligible for power input between 0.01 and 1.0 microwatts (45dbm to 30dbm). The results are considered to be valid within the microwatt region (50dbm to 20dbm).

Figures 9, 10, 11 and 12 give the variation of crystal resistance with bias. At 10 microamperes the value of the resistance obtained is about 3,000 ohms, and the results given by the two different methods are in good agreement. Crystal resistance determined by the two methods at 0.0 and 5.0 microamperes bias current are not in agreement as is shown by the average values given below.

Bias Current (microamperes)	0.0	5.0
Crystal resistance (constant-power-line method)	15,000	6,000 (ohms)
Crystal resistance (halving method)	10,000	4,500 (ohms)

The constant-power-line-tangent method is believed to give more accurate results. In using the halving method, no allowance was made for the increase in the 60 cycle noise voltage developed by the crystal with the decrease in bias below 10 microamperes. Above 10.0 microamperes the 60 cycle noise voltage was negligible. Below this value the increase was of the same order of magnitude as

# REPORT ON THE

## 1944-1945

It is a pleasure to report that the results of the research have been

very satisfactory. The work has been carried out in a most efficient

and systematic manner. The results are of great value and will be

published in the near future.

During the year 1944-1945 the following work has been

completed. It is a pleasure to report that the results of the research

have been very satisfactory. The work has been carried out in a most

efficient and systematic manner. The results are of great value and

will be published in the near future.

During the year 1944-1945 the following work has been completed.

It is

1944	1945	1946
1944 (1945)	1945 (1946)	1946 (1947)
1945 (1946)	1946 (1947)	1947 (1948)
1946 (1947)	1947 (1948)	1948 (1949)

The results of the research have been very satisfactory.

The work has been carried out in a most efficient and systematic

manner. The results are of great value and will be published in the

near future.

During the year 1944-1945 the following work has been completed.

It is a pleasure to report that the results of the research have been

that of the increase in crystal resistance. It is believed that this 60 cycle noise voltage increase is a crystal phenomenon caused by the presence in the crystal holder of 60 cycle magnetic fields. Shielding of the equipment gave no noticeable change in the effect.

The shape of the curve in Figure 12 suggests a power-law variation of  $R_x$  as a function of bias. The nature of this variation is clearly seen by plotting the curves of Figure 12 on log-log paper as has been done in Figure 22. Since the slope of the curves is a constant above 10.0 microamperes,

$$\frac{\Delta(\log R_x)}{\Delta(\log I)} = -a \quad (14)$$

Taking the limit as ,

$$\frac{d(\log R_x)}{d(\log I)} = -a \quad (15)$$

Converting Equation 15 to natural logarithms and integrating,

$$\ln R_x = \ln I^{(-a)} + C \quad (16)$$

and

$$R_x I^a = C, \quad (17)$$

Below 10.0 microamperes bias current the exponent  $a$  is not a constant but is a function of the bias and Equation 17 takes the form

$$R_x I^{[a=f(I)]} = C, \quad (18)$$



that of low resistance to impact is essential. It is not possible to  
 make the whole of the structure in a single material.  
 Some of the members in the central portion of the frame are  
 rigid, whilst others are flexible. The rigid members are in  
 the middle.

The shape of the frame in Figure 11 suggests a method  
 of construction of a frame of this type. The shape of this  
 is shown in Figure 12. The shape of this is shown in  
 Figure 13. The shape of this is shown in Figure 14. The  
 shape of this is shown in Figure 15. The shape of this is  
 shown in Figure 16. The shape of this is shown in Figure 17.

(12)

$$\frac{\Delta(\log R_x)}{\Delta(\log I)} = -a$$

Figure 12 is

(13)

$$\frac{\Delta(\log R_x)}{\Delta(\log I)} = -a$$

Figure 13 is

(14)

$$\ln R_x = \ln I + C$$

(15)

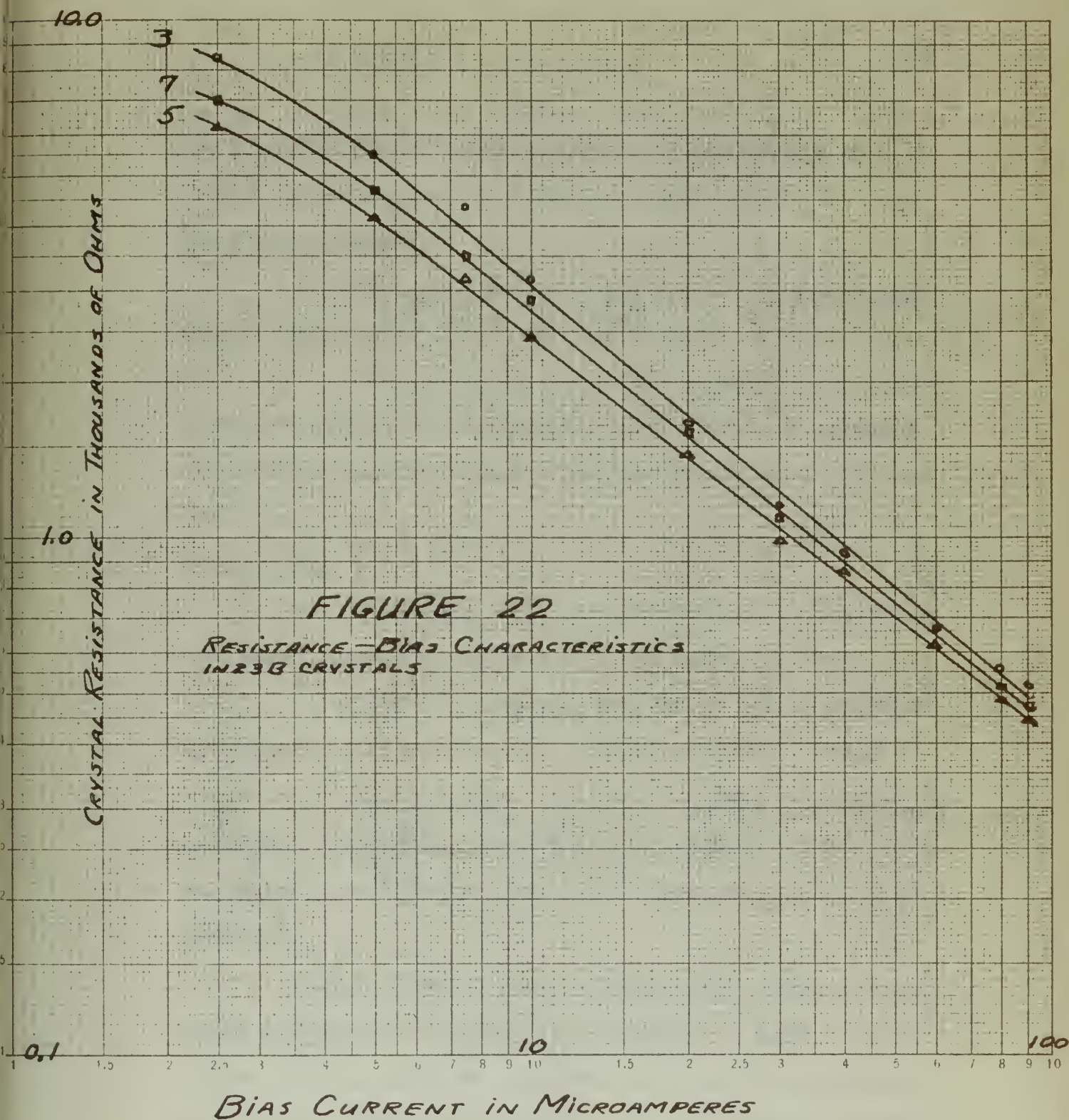
$$R_x I^a = C$$

Figure 14 is a diagram of the frame in Figure 11. The  
 shape of this is shown in Figure 15. The shape of this is  
 shown in Figure 16. The shape of this is shown in Figure 17.

(16)

$$R_x I^a = C$$







From Equation 18 the crystal voltage-current characteristic equation may be written as

$$V_x I^{(1-a)} = C, \quad (19)$$

where the exponent  $a$  is constant above 10.0 microamperes bias current and a function of the bias below this value.

#### Current Sensitivity

Figure 13 shows that the curves of current sensitivity as a function of bias current of 1M238 crystals are parabolic in shape. For conditions studied, the maximum is reached for a bias current of about 80.0 microamperes. This result is in agreement with data taken on other types of crystals by Meyerhof, Serin and Vough (21).

#### Voltage Output

Crystal voltage output is a function of the load and the bias as the results of Figures 14, 15, 16 and 17 show.

From Figure 14 it is seen that as the load is increased the voltage output increases and the point of maximum voltage output moves toward zero bias. The locus of maximum voltage output is shown in the figures. From this it is possible to interpolate the optimum bias conditions for the load into which a crystal is operating.

Figures 15 and 16 show that the crystal voltage output varies critically in the negative bias region. A point of zero output is seen to exist at approximately minus 0.05 microamperes bias current. This zero output point is seen to be near the point

From inspection of the crystal photographs it was found that the specimen was in fact a mixture of two different phases.

(192)

$$V_r T^{(1-\alpha)} = \bar{v}$$

where the exponent  $\alpha$  is constant and  $\bar{v}$  is a function of the rate of crystallization.

Experimental Results

Figure 1 shows that the rate of crystallization is a function of the rate of crystallization. The rate of crystallization is a function of the rate of crystallization. The rate of crystallization is a function of the rate of crystallization.

Figure 1

Conclusions

The experimental results show that the rate of crystallization is a function of the rate of crystallization. The rate of crystallization is a function of the rate of crystallization. The rate of crystallization is a function of the rate of crystallization.

Figure 1 shows that the rate of crystallization is a function of the rate of crystallization. The rate of crystallization is a function of the rate of crystallization. The rate of crystallization is a function of the rate of crystallization.

From inspection of the crystal photographs it was found that the specimen was in fact a mixture of two different phases.



of inflection of the d-c characteristic curve given in Figure 3, an expanded view of the negative half of the curve being given in Figure 23. Close inspection of Figure 23 shows the inflection point to be at approximately minus 1.0 microamperes.

In Figure 17 the slope of the curves show that IN23B crystals are very nearly square-law rectifiers within the region tested. For the 2,000 ohm load used the maximum voltage output condition is shown to be at 30 microamperes bias current. The 2,000 ohm load curve in Figures 1h and 2h show a maximum at approximately this same bias current.

To determine the validity of the above data for use with wide band amplifiers the TAA-16EA was replaced by a Ballantine voltmeter and decade amplifier, which had a band pass of from 30 cps to 300 kcps, and the information presented in Figure 1h was repeated for this wide band case. The results are shown in Figure 2h. Comparison of Figures 1h and 2h show that the results of the wide and narrow band cases are in agreement. The linear scale factor between the ordinates of the two sets of curves is due to the difference in amplifier gain.

From the above discussion it is seen that if the crystal output is to be voltage amplified, narrow or wide band, it is necessary that the crystal load be as large as possible, and that the bias be very near or equal to zero. If it is necessary to operate a crystal into a voltage amplifier whose input resistance is below 50,000 ohms it is advantageous to bias the crystal. Interpolation of the maximum voltage output curve in Figures 1h and 2h gives the necessary bias for the load to be used with the crystal.





NEGATIVE CRYSTAL VOLTAGE IN VOLTS

1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0

NEGATIVE BIAS CURRENT IN MICROAMPERES

0 0.5 1.0 1.5 2.0 2.5 3.0 3.5

FIGURE 23  
NEGATIVE D-C CHARACTERISTICS  
TYPE IN20B CRYSTAL  
CRYSTAL NO. 3.

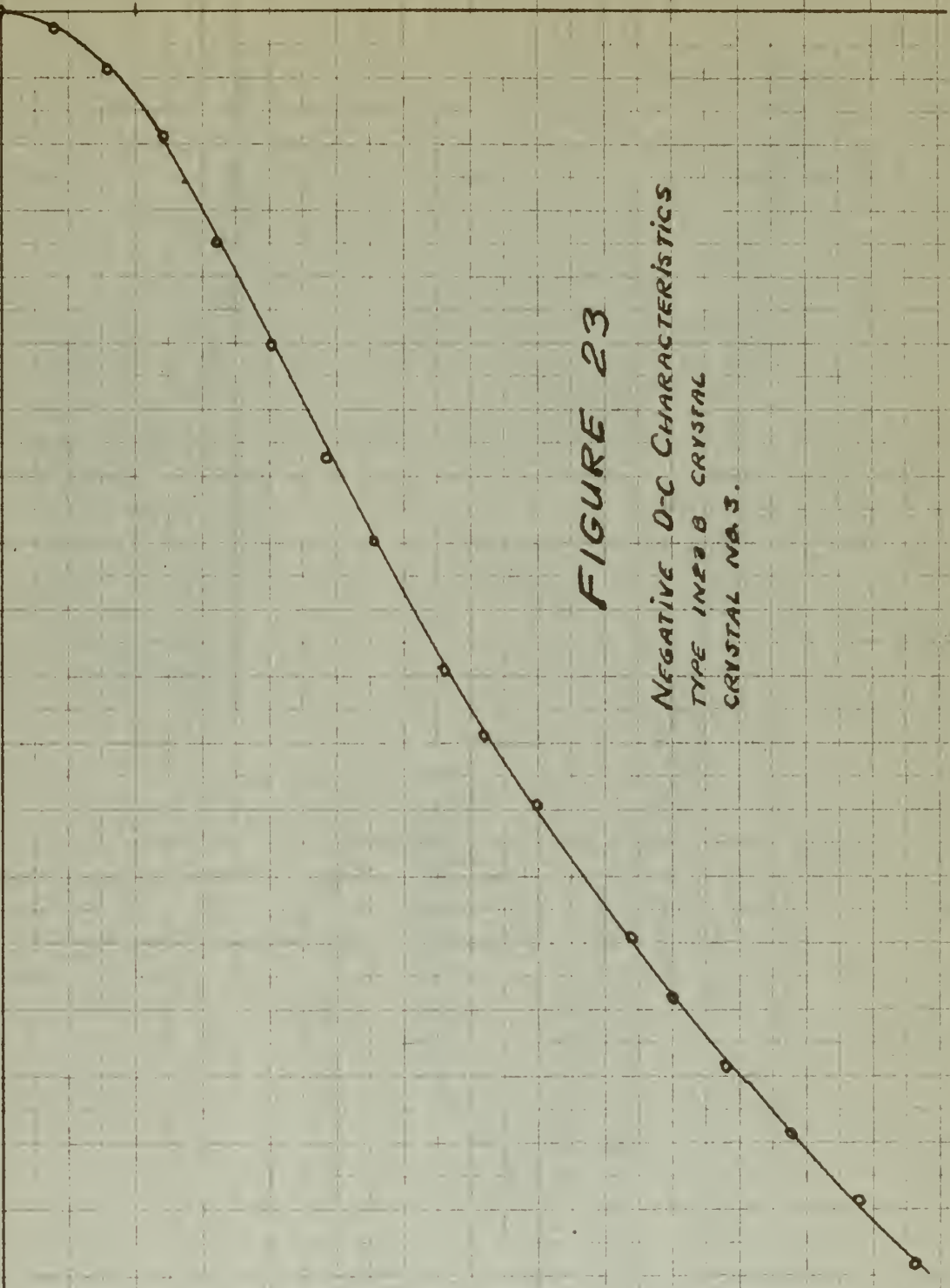


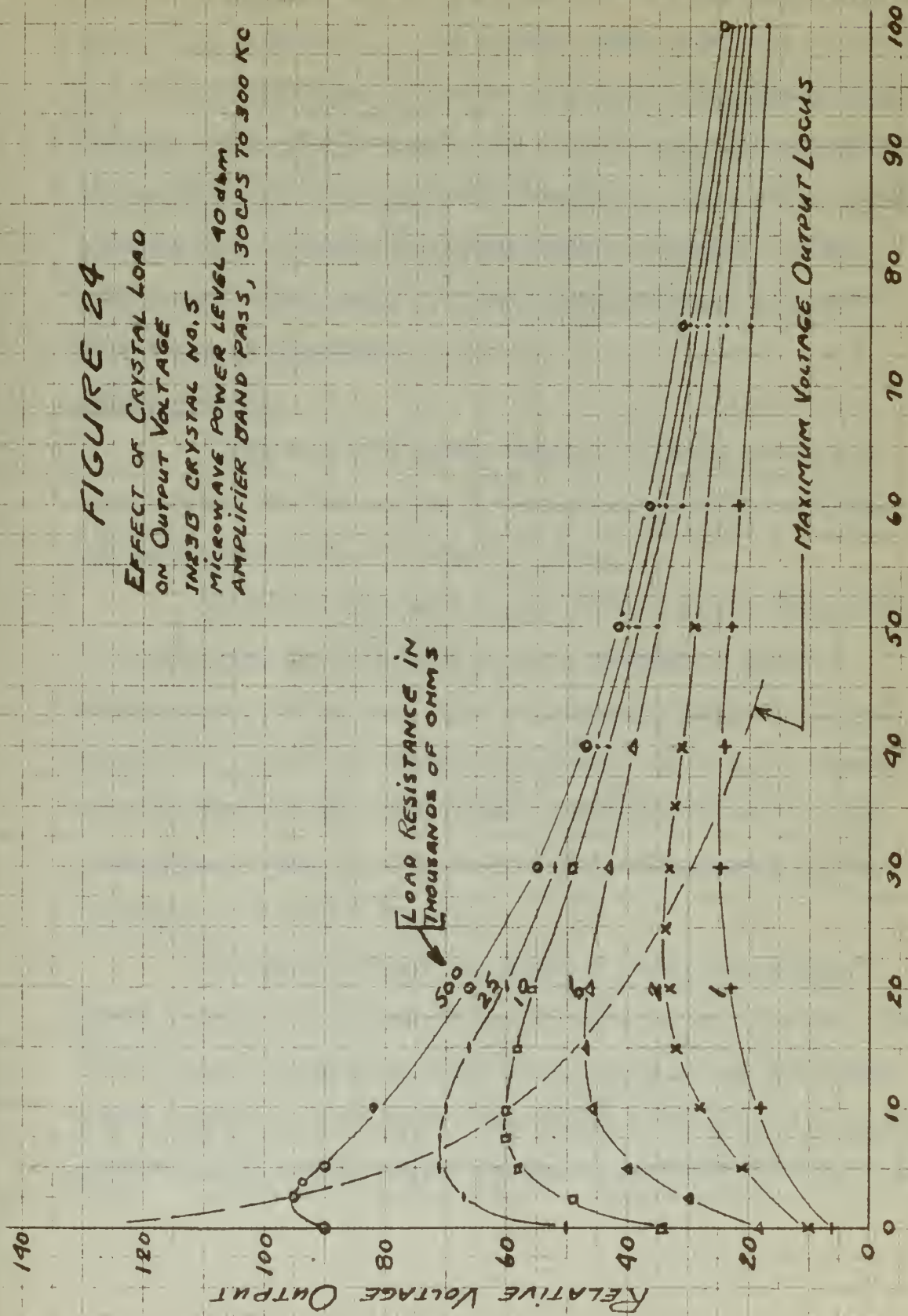




FIGURE 24

EFFECT OF CRYSTAL LOAD  
ON OUTPUT VOLTAGE

IN 23B CRYSTAL NO. 5

MICROWAVE POWER LEVEL 40 dBm  
AMPLIFIER BAND PASS, 30 CPS TO 300 KC

Bias Current in Microamperes





### Output Power

Maximum output power is a function of the crystal bias as is shown in Figure 19. The maximum output power bias condition for all crystals tested is in the region of 30 microamperes bias current. It is of interest to note that at this bias the crystal will be operating at a near maximum signal-to-noise voltage output ratio as will be shown in the next section. The slope of the power output curves below 20 microamperes indicates that control of the bias is necessary.

### Figure of Merit

There is a wide discrepancy in the Figure of Merit as determined by the two methods, computation from narrow band data and experimentally for the wide band case.

From the narrow band Figure of Merit curves (Figure 20) it is seen that best operation is to be obtained at about 20 microamperes bias current. This is reasonable since the current sensitivity curves show a similar increase. It is to be pointed out that there may have been present the effect of the 60 cycle noise voltage below 10 microamperes which could account for the large drop in  $M$  in this region.

In taking the data for Figure 21, care was taken to insure that the noise observed was not that due to 60 cycles. The 60 cycle noise voltage was nullified by superimposing the crystal output signal on the 60 cycle noise output and reading the superimposed signal-to-noise ratio. Though the zero bias condition shows a high

General Remarks

The present report covers the results of the studies made in the field of the history of the language of the people of the region of the present-day Republic of Armenia. The results of the studies made in the field of the history of the language of the people of the region of the present-day Republic of Armenia are presented in the present report. The results of the studies made in the field of the history of the language of the people of the region of the present-day Republic of Armenia are presented in the present report.

History of the Language

There is a wide divergence of opinion as to the date of the origin of the Armenian language. Some scholars believe that it is of Indo-European origin, while others believe that it is of Semitic origin. The present report is devoted to the study of the history of the Armenian language. The results of the studies made in the field of the history of the Armenian language are presented in the present report. The results of the studies made in the field of the history of the Armenian language are presented in the present report.

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Figure of Merit the crystal should not be operated at this point unless the amplification unit is capable of rejecting the 60 cycle noise component and all its harmonics.

If the 60 cycle noise voltage can be eliminated then crystal rectifiers can be operated at zero bias in conjunction with voltage amplifiers to give excellent signal-to-noise voltage output characteristics. However, if the 60 cycle noise voltage can not be rejected in some manner then the crystal should be operated at about 50 microamperes bias current for best signal-to-noise voltage output ratio.



1. The above information was obtained from the records of the FBI, New York Office, and is being furnished to you for your information.

It can be seen from Figure 1 that the

[illegible]

Figure 4: 40-day-old *Drosophila* with an overactive *UAS* *Ucp1* allele.

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largest forest in Europe with a maximum of 2000 years old.

## VI

### CONCLUSIONS

The load on the IN23B crystal and the type of amplification unit it feeds determines the bias at which the crystal should be operated.

The data compiled in this paper is believed to be sufficiently accurate for use in design of units using IN23B crystals as low-level detectors.

Further work is indicated to determine the cause and effect of the 60 cycle noise voltage developed by the crystal in the zero to 10 microampere bias region.

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## VITA

The author was born in Bay City, Michigan, June 2, 1920. He received his Associate Bachelor of Science degree from the Bay City Junior College in 1939. In 1940, he entered the U. S. Naval Academy and graduated in 1943 with the degree of Bachelor of Science.

Since 1943, he has served as a commissioned officer in the U. S. Marine Corps.

In 1947, he was admitted to the U. S. Naval Postgraduate School, Department of Ordnance Engineering, and upon completion of the first year of a three year course was admitted to the Graduate School of Engineering, The Johns Hopkins University for completion of the course.



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